IMPACT ASSESSMENT
OF
REDUCING GASOLINE VOLATILITY

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FINAL REPORT

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ABSTRACT

This report documents a study of the potential impacts on hydrocarbon emissions, on vehicle performance and on refining operations, investments and costs of restricting volatility of gasoline sold in California during the summer. Current volatility limits require a vapor pressure of no more than 9 psia. Assessments of impacts were made for restrictions of 8, 7 and 6 psia fuels in two future situations based on 1985 and 1990 crude and product forecasts. Results cover emissions effects in terms of vehicular exhaust and evaporative losses as well as non-vehicular evaporative losses. Vehicle performance effects are defined in terms of cold start, warm-up, driveability and safety considerations. Industry-level refining costs are developed in terms of raw material, capital and operating components. Typical refining situations are also examined.

ACKNOWLEDGMENT

As part of the management of this project, ARB scheduled bi-monthly meetings to review progress and results. Included at these reviews were three representatives from the refining industry, namely, Mr. H. F. Bowerman representing a group of independent refiners, Mr. W. T. Danker representing Chevron U.S.A. and Mr. T. A. Wandstrat representing Shell Oil Company. Time spent by these people and their associates in review of interim results as well as the study plan and premises provided useful criticism and suggestions. Their efforts, as well as those of the various ARB staff involved with this study, are gratefully acknowledged. Particular recognition must be made of the support provided by Mr. Eric Fujita, who acted as the technical project administrator for ARB.

In addition to the various staff within Bonner & Moore Management Science who assisted in this study, the project team included two subcontractors. Mr. R. W. Hurn of R-H Technical Services, Bartlesville, Oklahoma, who supplied expertise in the area of vehicle performance. Mr. Garrett E. Pack of Mittelhauser Corporation , El Toro, California, conducted the part of this study dealing with emissions impacts.

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SECTION 1

INTRODUCTION

This report documents a study of impacts resulting from potential restriction of summer gasoline vapor pressure in the State of California. The study was sponsored by the Research Division of the Air Resources Board (ARB) of the State of California under contract No. A2-051-32. Award of the study contract was made as a consequence of successful response to a solicitation dated October 27, 1981 titled, "Request for Proposal Entitled, Impact of Reducing Gasoline Volatility in California".

The general purpose of this study was to assess the impacts of lowering the allowable vapor pressure of gasolines during the summer period. Impacts included in these assessments are effects on hydrocarbon emissions, on vehicle performance, on crude requirements, on process investments and on refining costs. Three more restrictive vapor pressure levels than presently required were studied. Impacts were assessed for two future situations, namely projected environments for 1985 and 1990.

Beyond this introductory section this report contains three other sections and eight appendices. Section 2 presents a summary of results. Section 3 describes the main elements of the study approach as a framework for the reader's uses of the study results. Section 4 presents detailed results and methodologies. Appendix material contains supporting information.

The language and contents of this report assume that readers are familiar with the overall operations of refining crude oil and the problems of controlling air quality. The report, therefore, makes use of terms and references to processes used in petroleum refining and emissions control without definition. On the other hand, the summary of results presented in Section 2 does not require intimate knowledge of the technologies of refining or emissions control. A brief discussion of the importance and control of gasoline volatility is present here for those readers who are not familiar with the subject.

1.1 GASOLINE VOLATILITY, ITS PURPOSE AND ITS CONTROL

To function properly as a fuel for spark-ignited internal-combustion engines, gasolines must have certain volatility characteristics. To permit easy starting of a cold engine, the fuel must contain enough low-boiling hydrocarbons to provide, at ambient temperature, an air-fuel-vapor mixture that is rich enough to be ignited. Performance, after starting and during engine warm-up is also influenced by the concentrations of low-boiling constituents. If, however, the concentration of low-boiling hydrocarbons is not restricted, the fuel pump (after warm-up) may become vapor locked and fail to supply enough fuel to support combustion, causing the engine to stall.

With the recognition that hydrocarbon emissions adversely affect air quality, evaporative loss of low-boiling hydrocarbons from vehicle fuel systems has become another reason for concern about gasoline volatility. Two methods have been implemented to reduce fuel system losses.

One is the use of on-board vapor-collection devices. The other is the reduction of gasoline volatility below the level required to protect against fuel system vapor-lock. This latter method has been applied only in the State of California and only to gasoline used during the summer season. On-board vapor-collection devices have the theoretical potential of restricting evaporative losses regardless of fuel volatility characteristics and at all ambient conditions. These devices are in general use today; being essentially passive they require little maintenance and are relatively durable. Disadvantages include higher initial cost, potentially inadequate design capacity and potential for system deterioration and subsequent malfunction. Restricting gasoline volatility has the advantage of reducing losses throughout distribution and dispensing systems as well as from the vehicle fuel system. Disadvantages include higher fuel-manufacturing costs and poor vehicle performance. To understand the reasons for the increased cost of low-volatility gasoline, it is helpful to review the manner by which gasoline volatility is controlled during its manufacture and certain relevant economic factors.

As formulated, gasoline contains hydrocarbons whose boiling points range from 58°F to approximately 400°F.[1] The concentrations of the hydrocarbons in this range are controlled to satisfy a variety of quality characteristics, including volatility. This control is accomplished by the control of the refining processes which produce gasoline constituent stocks and by the careful blending of these

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[1] Small amounts of hydrocarbons boiling outside this range are usually present because physical separation processes are imperfect.

intermediate stocks to produce finished gasolines. Properties of blend stocks are determined largely by the nature of the processes involved but can be varied somewhat by adjusting operating conditions of those processes. Satisfying quality requirements of finished gasolines is achieved by controlled blending of available blend stocks.

Two measures of volatility are used to obtain desired cold-start and warm-up characteristics. These measures are Reid Vapor Pressure(1) and the volume-percent boiling below approximately 160°F(2). These same properties have been shown to relate to evaporative losses(3). They are closely related to the concentration of C_4 and C_5 hydrocarbons in gasoline and to somewhat lesser extent to the concentration of C_6's. Thus, control of gasoline volatility is related to the inclusion of these hydrocarbons in gasoline blend stocks.

In particular, most refiners have access to normal butane both as a purchased raw material and as a refinery stream. Historically, normal butane has been available as a by-product from natural gas processing and has been priced well below that of gasoline. Thus, the refiner has an incentive to blend the maximum amount of butane into his gasoline as limited by vapor-lock considerations. A further incentive is the fact that normal butane has a high octane rating and thus reduces the cost of meeting octane requirements of finished gasolines.

Summer gasoline in California presently cannot exceed a Reid Vapor Pressure (RVP) of 9.0 psi. If gasoline volatility is restricted below present levels, refiners must further restrict the amount of low-boiling hydrocarbons in their blends. This will prevent their using a relatively inexpensive component as well as require compensating for the octane quality it would provide. The first step toward meeting more restrictive RVP limits would be to restrict (or discontinue) blending butane as such. The second step would be to change processing to exclude butane presently contained in other blend stocks. This could require modification of existing separation facilities and/or the installation of new facilities to remove contained butanes. As a further step, extreme RVP limits could require removal of some C_5 hydrocarbons, which in most cases would require new separation facilities. Not only would the refiner incur additional costs for removal of these hydrocarbons from gasoline, there would be a loss in revenue since the rejected materials would be less valuable in their alternative dispositions. Achieving these alternate dispositions would require capital expenditures for new facilities such as storage tanks, loading racks, lines and pumps. Finally, additional crude and adjusted processing conditions would be required to make up for the gasoline volume lost by rejecting light hydrocarbons to other dispositions.

REFERENCES

(1) ASTM - D-323

(2) ASTM - D-86

(3) The Feasibility and Impact of Reducing Hydrocarbon Emissions by Reducing Gasoline Volatility, December 9, 1975, State of Californa Air Resources Board.

SECTION 2

SUMMARY OF RESULTS

Impacts assessed in this study and summarized in this section are limited to those addressed in the work statement of the original solicitation from ARB. They include impacts on hydrocarbon emissions, vehicle performance, refining operations and costs. Gasoline volatility restrictions were defined for this study in terms of vapor pressure limits. Three more restrictive levels than presently required for summer gasoline have been studied. These are limits of 8 psi, 7 psi and 6 psi. Two future situations were examined, namely projected environments for 1985 and 1990.

Emissions impacts were, in part, determined from estimates of changes in vehicle systems behavior. These estimates were made using relationships that have been developed from results of studies designed to associate vehicle emissions with fuel volatility characteristics. The volatility characteristics assumed for this study were those of the gasoline blends derived from projections of future refinery operations under the various vapor pressure levels mentioned above. Future refining operations were determined by analyses of the behavior of mathematical models of California's refining facilities.

Quantifying impacts of restricting summer gasoline volatility was the purpose of this study. Certain qualitative results are apparent from making these assessments, namely:

1) Limiting vapor pressure to the extreme of 6 RVP would be counter-effective in reducing hydrocarbon emissions. Limiting vapor pressure to 7 RVP may also be counter-effective.

2) Exhaust emissions from vehicles would increase if vapor pressure were restricted to 7 RVP, or less.

3) Evaporative emissions from vehicles pre-dating late 1970 models would improve with reduced vapor pressure. Later model-year vehicles would probably show little effect.

4) Available data on vehicle performance and emissions is lacking for fuels with low vapor pressures. No data are available for future vehicle designs.

5) Data for existing models indicates that vehicle performance will suffer if vapor pressure is restricted further than allowed by present regulations.

6) At lower limits of vapor pressure, decreased driveability and potential for greater explosion hazard of fuel tank vapor impact safety considerations.

7) Manufacturing costs of gasoline will increase significantly if vapor pressure is restricted further than allowed by present regulations.

Summaries of results from assessment of the various impacts are presented in following subsections. This section includes a summary of issues not covered as well as some that were suggested by the study itself. Finally, there are subsections presenting conclusions and recommendations.

It should be emphasized that costs identified in this study pertain to refining impacts. Costs related to automotive design and production and socioeconomic benefits relating to changes in air quality are not addressed.

2.1 EMISSION IMPACTS SUMMARY

A negligible reduction or even an increase in vehicle exhaust emissions is indicated for vapor pressure limits down to 8 RVP. With further reduction, in the 7 to 6 RVP range, exhaust emissions are shown to increase by as much as 25 percent. For vehicles pre-dating the late 1970's, evaporative emissions would be progressively reduced by as much as 50 percent. Evaporative emissions from late 1970 models and newer vehicles probably would be negligible. This is because vehicles equipped with current evaporative control technology show little reaction to fuel volatility changes.

Emissions from non-vehicular sources would be reduced if gasoline vapor pressure were further restricted. These sources include refining blending and storage tanks, terminal and transportation facilities and dispensing operations.

Estimated emissions from all sources are summarized in Table 2-1. Also shown is the net change in estimated emissions at limits of 8, 7 and 6 RVP.

The overriding effect of increased exhaust emission estimates at lower RVP limits is illustrated graphically in Figure 2-1. As shown, total reactive organic emissions for 1985 are at a minimum between 8 and 7 RVP. For 1990 the minimum is between 9 and 8 RVP. In both years, evaporative losses from vehicular and non-vehicular sources decrease with reduced maximum RVP but are offset with the increased emissions from vehicular exhaust.

Because vehicular evaporative emission estimates include the assumption that post-1979 vehicles will respond to RVP changes as indicated for pre-1979 vehicles, reduction in estimated evaporative emissions should be considered as a maximum benefit for lowering RVP limits. If no reduction in evaporative emissions were realized, total emission would increase with any decrease in RVP limits.

Estimates in Table 2-1 and Figure 2-1 are based on adjusted model-predicted results. As discussed in Section 4.1, without this adjustment for model bias, gasoline volatilities predicted by model results at 9 RVP disagree with data from gasoline surveys. No explanation for this discrepancy could be determined from an examination of the data

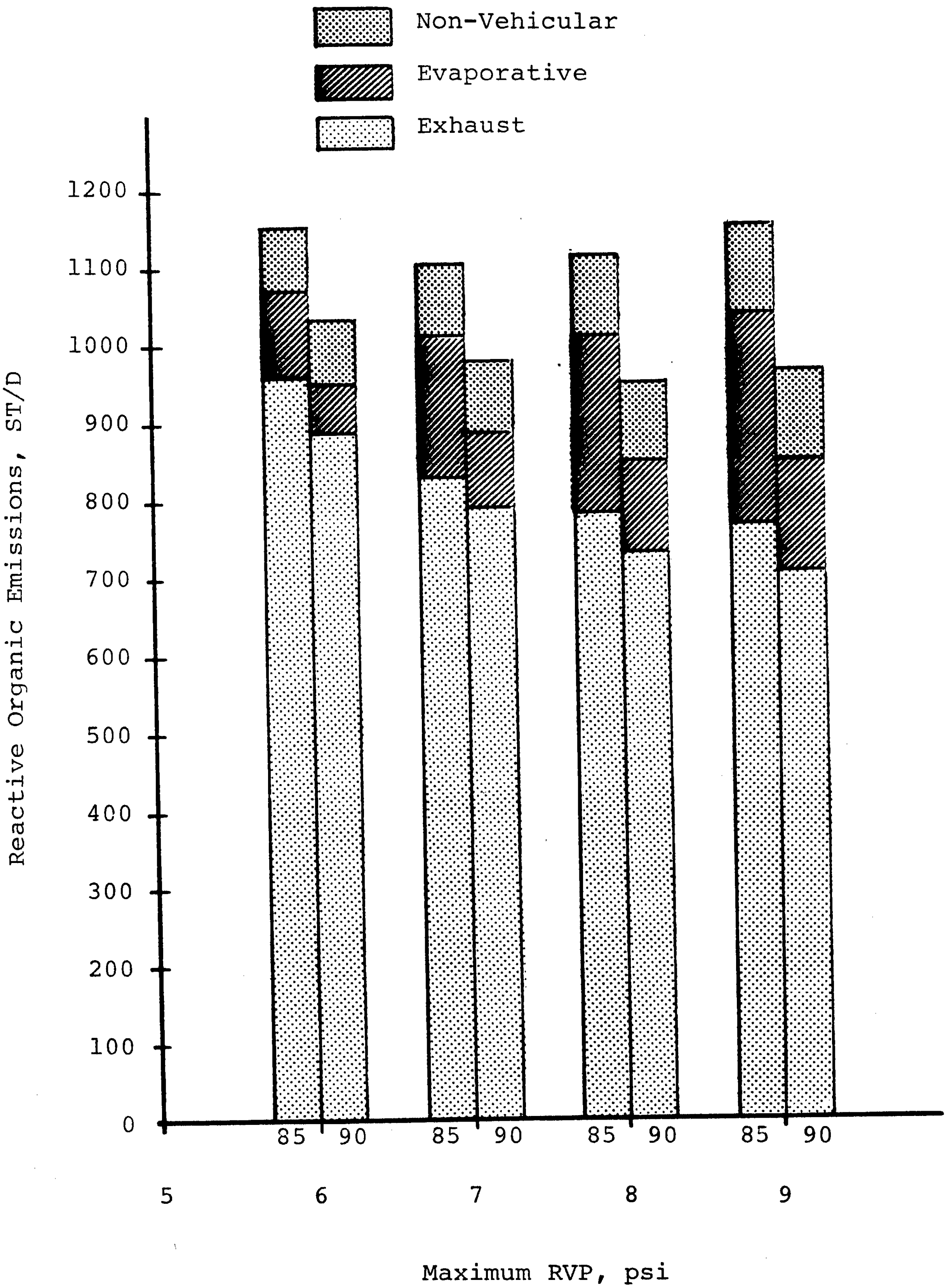

Figure 2-1. RVP Effect on Estimated Emissions (Using Adjusted Volatility Results)

TABLE 2-1

REACTIVE ORGANIC EMISSIONS SUMMARY FROM VEHICLE AND NON-VEHICULAR SOURCES

(Short Tons Per Day)

Year	RVP	Vehicle Exhaust[1]	Vehicle Evaporative[1]	Non-Vehicular Sources	Total	Reduction	Cumulative Reduction
1985	9	768	272	113	1153	-	-
	8	789	226	101	1116	37	37
	7	835	180	92	1107	9	46
	6	959	115	80	1154	-47	-1
1990	9	710	139	114	963	-	-
	8	737	114	101	952	11	11
	7	793	93	93	979	-27	-16
	6	891	65	77	1033	-54	-70

[1] Using adjusted volatility results.

employed in the model or the survey samples. Since there is no reason to think that gasoline volatility (at constant RVP) should change significantly in the future, emissions estimates were prepared with adjusted, as well as model-predicted, results.[1]

2.2 VEHICLE PERFORMANCE IMPACTS SUMMARY

If 1980's/90's vehicles respond as do earlier models, vehicle performance would suffer from volatility reduction, particularly at the lower levels that were studied. As with the assessment of emissions, data from late-model production vehicles are vital to reliable projection of performance impacts. Lacking new information, it can only be assumed that performance will be degraded if vehicles are required to operate on fuels having volatility significantly below that typical of current fuels. The degree of degradation could be negligible to severe depending upon RVP level and could be markedly vehicle dependent as new air-fuel and engine control technologies are introduced.

Safety impacts of volatility reduction involve driveability and a possible hazard of fuel tank explosion. Poor acceleration and stalling would be experienced with sensitive systems and with very-low-volatility fuel. Recognizing the critical importance of the performance factor, data on driveability should be obtained with late-model vehicles using fuel at RVP levels in the low range of interest.

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[1]Emission estimates from both sets of volatilities are presented in Section 4.1. Estimates using the unadjusted volatility results indicate some improvement in exhaust emissions at 8 RVP.

TABLE 2-2

REFINING COST IMPACTS FOR
REDUCED RVP LIMITS
(Above Base Case)

	Max RVP for 1985			Max RVP for 1990		
	8	7	6	8	7	6
Annual Costs, MM$/Yr.[1]						
Raw Materials	40.7	83.5	144.3	37.6	79.7	144.7
Capital Related	24.2	57.3	108.2	32.5	68.8	114.4
Variable Operating	0.2	0.4	0.7	0.3	0.7	1.0
Total	65.1	141.2	253.2	70.4	149.2	260.1
Added Gasoline Costs, $/BBL						
Raw Materials	0.28	0.58	1.00	0.27	0.58	1.05
Capital Related	0.17	0.40	0.75	0.23	0.50	0.83
Variable Operating	0.00	0.00	0.00	0.00	0.00	0.01
Total	0.45	0.98	1.75	0.50	1.08	1.89

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[1]Assumes summer period is 6.4 months.

be met, regardless of the cost of doing so, because refining as a whole does meet demands. On the other hand, an individual refinery can choose to change its market share of a particular product.

Another reason that these industry-average costs may not reflect costs for a given refinery is the influence of complexity, location and, to some extent, size. Complexity relates to processing flexibility, location to crude supply. A limited discussion of individual refinery impacts is made later in this section.

At the industry level, as shown in Figure 2-2, approximately half of the cost increase for reducing vapor pressure is for increased crude consumption. The increase derives from having to process more crude to compensate for gasoline volume lost when lowering vapor pressure. Another small increased need for crude relates to slightly more process energy being required to control gasoline vapor pressure and to process the additional crude mentioned above.

Table 2-3 shows the crude oil increase associated with lowering vapor pressure. The impact is shown as the daily summer-time increase for the State and as a fraction of the gasoline production. Because processing changes produced small increases in by-product LPG and petroleum coke, crude increases are also shown after adjusting for the energy-equivalent volume of by-products. This latter is based on the fact that these by-products represent energy supply which would theoretically decrease overall crude requirements, at constant energy supply.

Capital related costs shown in Figure 2-2 and Table 2-2 pertain to expanded and new process capacity needed to meet lower vapor pressure restrictions. The capital required is summarized in Table 2-4. Results are presented as total investment impact for the State and as investment required per barrel of gasoline, to allow estimation of total investment at other levels of gasoline demand.

Also shown in Table 2-4 are investment impacts deriving from facilities probably needed in storing and transporting low-boiling hydrocarbons rejected from gasoline blending in order to meet more restrictive vapor pressures. These facilities might be installed by refiners or by other potential consumers of these low-boiling hydrocarbons. Thus, they are shown as distinct from refining investment impacts.

Any given refinery could be expected to show effects different from the industry-average results presented above. These differences would derive from the particular crudes processed, the particular processes in place and the effects of market prices and market shares for that refinery. A limited examination of the range of specific refinery effects of changing gasoline vapor pressure was made by assuming that each refinery would adjust his operations without making capital investments.

A summary of these minimum action effects is shown in Table 2-5. The effects are shown as the added per-barrel costs of manufacturing gasoline to varying vapor pressure limits. As shown, changing RVP has a similar effect on gasoline cost increase regardless of the refining situation.

TABLE 2-3

CRUDE REQUIREMENTS
(Above Base Case)

	Max RVP for 1985			Max RVP for 1990		
	8	7	6	8	7	6
Daily Increase, MBPD	10.0	21.3	35.6	8.6	17.7	33.1
,percent of gasoline	1.3	2.9	4.8	1.2	2.5	4.7
Adjusted Daily Increase						
, MBPD	6.3	13.1	21.9	5.7	12.2	21.8
,percent of gasoline	0.8	1.7	2.9	0.8	1.7	3.1

TABLE 2-4

CAPITAL REQUIREMENTS
(Above Base Case)

	Max RVP for 1985			Max RVP for 1990		
	8	7	6	8	7	6
Refining Facilities						
, MM$	79	185	345	104	223	372
, $/BBL of gasoline	106	248	463	146	314	524
Disposal Facilities						
, MM$	13	25	58	13	27	50
, $/BBL of gasoline	17	33	78	18	38	70
Total Capital, MM$	92	210	403	117	250	422
, $/BBL of gasoline	123	282	541	165	352	594

TABLE 2-5

ADDED COST - MINIMUM ACTION CASES
($/Bbl of Gasoline Production at Stated Vapor Pressure)

Refinery Situation	Maximum Allowed Vapor Pressure 8 RVP	7 RVP	6 RVP
Complex Refinery running Composite Crude	0.27	0.68	1.46
Cracking Refinery running Mixed Crude	0.30	0.61	0.99
Cracking Refinery running Low Sulfur Crude	0.37	0.66	1.22
Cracking Refinery running Wilmington Crude	0.30	0.60	1.14
Cracking Refinery with small alkylation running Wilmington Crude	0.30	0.61	1.15
Cracking Refinery running Alaskan North Slope Crude	0.30	0.60	0.93
Hydroskimmer with large reformer	0.27	0.68	1.79
Hydroskimmer with small reformer	0.18	0.66	1.25

2.4 ISSUES NOT COVERED

Several issues of related importance were not included in this study. Most of these were beyond the scope of the study. One, sensitivity of results to alcohol blending, was not investigated because experimental data indicate malfunction of fuel tank canisters when alcohol vapors have been adsorbed, because adding alcohol has a marked increasing effect on vapor pressure and because octane effects were studied as a sensitivity parameter.

One issue is the question of customer reaction to potential deterioration of performance and higher gasoline cost. If customer reaction were to influence buying preference toward diesel-powered vehicles, a shift in gasoline and diesel fuel demands would occur. No attempt was made in this study to assess the effect of performance and fuel cost on buyer behavior.

Another subject not covered is the engine-design cost increases which may be associated with lower-volatility gasolines. No attempt was made to assess such costs. Auto manufacturers would, however, have to consider the measures to be taken to compensate for driveability and interactions between warm-up schedules, emissions control and performance.

Although ARB work has recognized the importance of Front-End-Vapor-Index (FEVI) in correlating emissions and fuel properties, this study has considered changing maximum vapor pressures and allowing FEVI to fall where it may. Industry, on the other hand, might be able to lower FEVI by selective control of both vapor pressure and low-boiling characteristics.

SECTION 3

STUDY APPROACH

The purpose of this section is to provide the reader with a general understanding of the major premises and approach used in the study. This understanding is important in judging the relevancy of results as well as their limitations. Section 3 material has been organized to parallel that used in presenting the result summaries in Section 2 and detailed results in Section 4.

3.1 EMISSIONS ESTIMATIONS

3.1.1 Vehicle Classification

Mobile sources from which emissions would be impacted by change in gasoline volatility include:

- Light-duty passenger vehicles
- Light-duty trucks
- Medium-duty trucks
- Heavy-duty trucks, and
- Motorcycles

Diesel-powered units excluded

Three sources of hydrocarbon emissions are recognized within each of these classes: 1) exhaust (or tail-pipe), 2) fuel tank and carburetor evaporative losses, and 3) crank-case emissions. The latter, crankcase emissions, are relatively unaffected by fuel volatility, and additionally are assumed totally controlled in later-year equipment. Crankcase emissions are therefore considered in this study to be unaffected by volatility reduction. Both exhaust and evaporative emissions are affected. Each is affected differently and therefore is considered separately in the study.

While emissions factors have been developed for each of the categories of vehicles recognized above, experimental work concerning effects of volatility on emissions has been limited to light-duty passenger vehicles.[1] However, this one class is dominant as a vehicle emissions source, accounting in 1980 for some 70 percent of all vehicular hydrocarbon emissions as estimated by the ARB. Moreover, control technology employed in light-duty trucks has closely followed that of light-duty passenger vehicles and therefore the volatility/emissions relationships that are established for the passenger vehicles can be assumed to apply to light-duty trucks. When light-duty truck emissions are grouped with light-duty passenger vehicle emissions, the two classes account for about 85 percent of all 1980 vehicular hydrocarbon emissions as estimated by ARB. At this point, lacking an experimental data base to describe the volatility impact on emissions from medium-duty and heavy-duty trucks and from motorcycles, the decision could have been made to assume no influence and, in effect, hold the truck/motorcycle fraction (roughly 15 percent) of vehicular emissions unchanged by the different volatility levels. That approach was not chosen because it is recognized that both evaporative and exhaust emissions in all classes of vehicles are influenced by factors that are common to all classes and that the direction, if not degree, of influence is, in the main, common to all.

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[1] The statement refers to systematic experimental work of nature and scope to yield information that could be extrapolated to the general vehicle population. No attempt was made to uncover experimental data that might be more directly applicable to vehicles other than light passenger types.

For purposes of this study, therefore, the volatility/emissions relationships for light-duty passenger vehicles--with appropriate selectivity and matching--were used in estimating effects on emissions from all other vehicle classes.

3.1.2 Fuel Factors

Very early work to relate volatility to emissions established that both exhaust and evaporative emissions were related to volatility measured not only as RVP but also as one or more volatility parameters that reflect more fully the front-end and mid-range distillation characteristics of the fuel. It was therefore relevant in this study to examine how fuels were changed in distillation behavior as well as in RVP value. Several expressions of volatility (additional to RVP) have been found useful in relating emissions. These include:

- "Modified Reid Vapor Pressure"[1],
- "Front-End Volatility Index"[1],
- Various expressions of vapor/liquid ratio, and
- Percent evaporated at some defined temperature in a specified distillation.

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[1]For a definition of these expressions see Appendix G.

Each of these expressions has been found useful in one or another varied correlations. However, of the choices, RVP used alone, and RVP plus the value for percent evaporated at 160°F[1], have been found to be the most generally useful.

These expressions of volatility have the advantages that:

1) they are available from information typically gathered and used in refinery operations and fuel analyses, and

2) they permit generally good correlation of volatility with exhaust emissions and with both diurnal (fuel tank) and with hot soak (carburetor) evaporative losses.

RVP and the associated value of percent distilled at 160°F were therefore chosen as the fuel parameters to be used in estimating volatility effects on vehicular emissions. These two measurements are combined to produce a calculated property called front-end-volatility index (FEVI). Vehicular emissions have been estimated by relating FEVI with emissions data and projecting impacts of lower RVP fuels based on their estimated FEVI's.

Details concerning the data and calculation procedures are presented in Section 4.1.

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[1] The value of 158°F often is referenced instead of 160°F. The latter (160) results from rounding 158°F which corresponds to 70°C, the accepted metric-based reference point for this volatility expression. This temperature difference is masked by limited accuracy of model results.

3.1.3 Data Base and Calculation Methodology

Two major studies by which vehicular emissions were related to gasoline volatility were made in the late 1960's to late 1970's using test vehicles that, in the aggregate, represented model years 1968 through 1977. (1) (2) (3) In each of these studies, RVP and other volatility characteristics were varied systematically to allow analysis of the several relevant volatility variables. Later studies have focused upon the effects of fuel volatility when alcohols are blended into gasoline.

3.2 VEHICLE PERFORMANCE ASSESSMENT

Cold-start and warm-up performance are closely related to fuel volatility, and vehicles in the U.S. auto population have been designed to operate most satisfactorily with gasolines that have volatility characteristics as currently marketed. Vehicle performance is likely to be adversely affected by reduction of vapor pressure limits on summer gasolines. The following subsections discusses the data pertaining to vehicle performance and the methodology for assessing vapor pressure impacts on performance.

3.2.1 Data Base

Experimental work, circa 1970, to relate volatility and emissions included some study of effects on driveability.(4) However, the driveability study was neither as extensive nor as fundamentally connected as the emissions study and results were quantifiable only within quite broad limits. Moreover, engine design, vehicle power/weight ratios, emissions control technology, and interactive vehicle warm-up and emissions controls have changed markedly since the 1969-1970's work was done. Given these considerations, experience gained in the earliest volatility/emissions/driveability studies is useful only in a broad qualitative sense.

Additional data are available from tests conducted by the Coordinating Research Council (CRC)[5] and from less extensive studies made within the petroleum industry.[6][7] The CRC tests were run using 16 cars roughly representative of the 1980 model-year market share distribution among the three major U.S. manufacturers. Driveability testing was comprehensive in coverage of engine malfunctions and employed quite sophisticated rating and data analysis techniques. Unfortunately for the purposes of this study, the gasolines that were used in the CRC study were within the range of commercial U.S. gasolines and do not provide data that are directly applicable to fuels at volatility levels well below 9 RVP. Nonetheless, the CRC data provide significant insight into the volatility parameters that are at work affecting driveability and permit some qualitative judgments to be made concerning volatility effects within the RVP range of interest in this study.

Data available from Chevron[6] were obtained using 1973 through 1976 model automobiles and fuels that included one fuel at 6.5 RVP. The Chevron data are therefore of great value to the assessment to be made although they are in no sense definitive of effects to be expected with vehicles dominant in the late 1980's.

3.2.2 Methodology

The methodology used herein in assessing volatility effects on driveability is essentially non-quantitative. Findings in the studies that are referenced were used to identify the volatility parameters that historically are found to govern engine performance; subsequently, the projected 1985-1990 fuels were examined with regard to those parameters so identified and the driveabiity/volatility relationships that have been developed. These were interpreted broadly and with due recognition of two important facts about engines, vehicles, and systems control factors that critically influence the driveability/volatility relationship. There are:

1) These critical interactive factors have not been examined in definitive studies of late model cars, and

2) Automotive systems are in a period of design transition and there exists no basis for projecting volatility effects to those designs that will evolve.

In consideration of both the imprecise character of existing data and the uncertainty for future systems behavior, there has been no attempt to differentiate driveability effects at discrete levels of volatility reduction. The discussion in Section 4.2 refers to effects that might be associated with volatility reduction from 9 to 6 RVP. Neither the point within that range at which effects would become significant nor the severity of the effect can be further identified or quantified at this time. Experimental work with late model vehicles is essential to define further the effect of reduced volatility at any discrete level within the 9 to 6 RVP range.

3.3 REFINING ASSESSMENTS

As with the study of any industrial segment, analysis of the petroleum refining sector in the State of California involves simplifying assumptions. These assumptions obviously can restrict the accuracy and applicability of results. Other assumptions, primarily related to modeling refining technologies, can produce inaccuracies and can also limit the range of applicability of results. In addition, it must be recognized that product demand and crude supply forecasts needed to define future situations are of unknown accuracy.

3.3.1 Refinery Modeling

Two types of models were employed in the assessment of refining impacts. One was a linear programming model of the composite of all California refiners presently in operation. The other is a refinery process simulator which was used to analyze several specific refining situations.

3.3.1.1 Linear Programming Model

An LP model was employed to assess the response of the refining industry as a whole. This model was designed to require satisfying forecasted product demands using crudes as projected to be available. Four levels of gasoline vapor pressure for each of two future years were examined. Decision variables in the model included varying process operating conditions, dispositions and allocation of process intermediate stocks and blend stocks and installation of new process capacity and/or expansion of existing capacity. By relying on the optimizing procedures of linear programming, the solution for a particular case represents the best balance among operating, raw material and capital costs for minimizing the overall cost of meeting future product demands at each RVP level. Refining impacts were determined from comparisons of results from cases for a given future year. A base case, with gasoline vapor pressure at 9 psi, represents industry operations if no change in present regulations occurs. Differences between a case at lower RVP and the base case provide measure of the increase in operating costs, crude requirements, and capital investments needed to meet the more restrictive volatility limits under study.

Yields and properties of streams from distilling available crudes reflected groupings into four categories. Three represented low, medium and high sulfur-content categories and the fourth represented Alaskan North Slope (ANS) crude. Volumes of the first three were set by crude availability forecasts. ANS was allowed to vary since it was defined as the marginal crude source for the West Coast. Refinery processing was represented generically and does not depend on any specific licensor's technology.

Operations associated with gasoline manufacture as well as those for other major fuel products were represented in detail to reflect quality limitations. All major processes from crude distillation through product blending were depicted. The capacities of these processes were defined to represent the combined capacities of similar processing in all operating refineries. To characterize the future capability of these plants, current capacities were adjusted to reflect facilities under construction and announced for future installation.

Non-fuel product operations were simplified to reduce model size and, thus, computation and analysis costs. Petrochemical feedstock interfaces involved a reasonable selection of all possible refinery intermediates and used simplified process depictions. Specifically, benzene, toluene and xylene production was modeled as a single yield structure representing extraction and distillation separations of a single reformate producing a combined aromatics extract plus light and heavy raffinates. The combined aromatics stream was assumed to satisfy the combined demands for all alkylbenzenes.

Production of lube oils, waxes, asphalts and solvents was represented by a set of simple recipes (formulas) without regard for the downstream processing requirements after crude distillation.[1]

A single model of regional refining capability ignores the peculiarities of each refinery in that region. It implies a degree of intermediate product exchange flexibility not utilized in practice. It ignores the degree to which specific crudes are segregated by being charged to specific refineries. It obscures the effects of varying complexity. Any attempt to define future graduation in refinery complexity would, however, be difficult to support because existing and future complexity patterns are the results of many variables. For example, the Small Refiners Bias (SRB) has influenced the viability of small simple refineries. Elimination of the SRB with decontrol of crude prices and removal of allocation regulations has caused some

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[1]Processing such as asphalt blowing, lube hydrotreating, etc., were ignored and were excluded from composite configuration detail.

small refineries to go out of business.[8] Competition from foreign refined product imports, as another example, could have a variety of effects on domestic refining.

The interaction of refineries of differing complexities is not well documented in publicly available sources. The degree to which two refineries of differing complexities in a given location compete for raw material supply and market shares is dictated primarily by considerations other than refinery complexity. Therefore, defining how a refinery of a given complexity might have to change to meet some new situation does not indicate what other refineries of similar complexity will do.

By modeling California's refining capability as a single refinery, it is possible to determine, in general, what changes to existing capacity and what new processing would be needed in that region. It is not, however, possible to say within which refineries of the region these configuration changes would occur because of this essential simplifying assumption and because of factors outside of the scope of this study.

Refining representations were modeled without regard to the degree of integration or the variety of configurations or ownership type. No special recognition of the "small refiner" was employed. While this simplifying assumption causes results to misstate the impact on small refiners, it is the uniqueness of such situations which prevents their examination within the scope of this study and without access to data confidential to each refiner.

Process options in the model are based on current technology. It is likely that areas of new technology will surface over the next decade. Their exact form is, however, impossible to predict at this time. Technological breakthrough has, therefore, not been included in this study.

3.3.1.2 Refinery Simulator

Individual refining situations have been analyzed by using a refinery simulator system developed for rapid material balance and refining cost estimating. Unlike the LP model employed for industry-level assessments, the refinery simulator does not utilize optimization for selection of operating conditions, stream dispositions or for product yield determination. Instead it requires the user to input process capacities and operating conditions as well as specific crude compositions and rates. Product yields are then determined by utilizing available processes and feeds under a set of predetermined priorities for a limited set of alternatives. Process yield relationships, stream quality distinctions and product quality limitations are greatly simplified in order to provide rapid computation and low-cost results.

Use of this tool in this study has been the examination of the impact, on a selected set of theoretical refinery situations, of operating in the overall refining environment of lower vapor pressure limits but without expending capital for basic refining. The overall refining environment was defined by using incremental product costs from the 6-RVP-1990 LP model results as refinery netback values. This implies that marginal product markets are set by incremental refining costs. Impacts on the capabilities of these theoretical refinery situations were determined as changes in revenues and changes in gasoline producibility which would be the primary cause of revenue changes. At reduced vapor pressure limits, additional processing and capital costs also accounted for facilities which would be needed to separate light hydrocarbons from certain gasoline blend stocks.

Approximations of product prices and quality correction costs were used in conjunction with refinery simulation models to estimate the profitability effects and product distribution changes for several typical refinery situations. Effort was made when specifying these individual refinery situations to not represent any specific existing refinery in California. The objective was to specify refinery situations that span those in operation.

Eight situations were selected:

1) Five cracking refiners, each with a different crude type.

2) Two medium-sized hydroskimming refineries, each with a different crude type.

3) A single moderately large complex refinery running the same proportions of four crude types as defined for the LP model.

3.3.2 Study Premises

Three sets of premises have been adopted in making this study. They pertain to forecasted product demands and crude supply, to certain economic and financial assumptions and to maintaining an energy balance while changing maximum vapor pressure limits. These are discussed further in the following subsections.

3.3.2.1 Product Demands and Raw Material Supply

All major fuel product and non-fuel product demands used in this study were forecast on the assumption that changes in vapor pressure limits would not change the cost of production sufficient to change the overall behavior of consumers. Thus, trends of recent demand history have been projected in relationship to pertinent econometric factors. The resulting demands (adjusted for historical movements into and out of the state) were imposed as fixed requirements on the industry-level LP model.

Two by-products were identified as LPG (propane) and petroleum coke and were allowed to vary as dictated by conditions for each case studied. While a reason for this approach relates to computational convenience[1] each of these by-products represents a separate forecasting problem. LPG production, as reported, apparently accounts for propane included in certain crude deliveries that does not show in

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[1]The degrees of freedom allowed by these prevent unrealistic operating conditions and/or failure to achieve a feasible solution.

crude assay data. Experience has shown that forcing an industry model to meet reported levels of LPG production causes irrational model behavior. Petroleum coke, because some part is typically exported, does not compete totally with other sources of industrial energy. Coke, and, perhaps sulfur, can be viewed as the only significant by-products of the refining industry.

Crude supply was forecast by projecting recent trends in domestic field production rates except where enhanced recovery methods are being applied. In those cases, allowances were made by reducing decline rates. Areas of potential new production, particularly that of off-shore Santa Barbara, were recognized as future sources. Foreign crude imports were projected to continue to decline. In particular, it was assumed that Arabian Gulf crude would be discontinued by 1990. Alaskan North Slope crude, which was projected to be abundant enough to meet the balance of crude requirements at least through the end of this century, was assumed to replace the importation of Arabian Gulf crude to the West Coast. North Slope crude was, therefore, employed in this study as the marginal crude source.

Details of product demand and crude supply fore-casts are contained in Appendix A and B, respectively.

3.3.2.2 Economic and Financial Assumptions

All economics in this study are in terms of constant 1982 dollars. Raw material costs and product reve-nues are based on a laid-in cost of $29.80 per barrel for Alaskan North Slope crude and on recent market quotations

REFERENCES

(1) Bureau of Mines, U.S. Department of Interior RI 7291, 1970

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(3) The Effect of Fuel Volatility Variations on Evaporative and Exhaust Emissions, Exxon Research and Engineering, May 1979, API #4310

(4) Study of the Interaction of Fuel Volatility and Automotive Design as They Relate to Driveability. Ethyl Corporation, April 1972. NTIS #PV 210 353. (Report of a Study sponsored by the American Petroleum Institute.)

(5) Effects of Fuel Volatility on Driveability of 1980 Model Cars at Low and Intermediate Ambient Temperature, CRC Report No. 524. March 1982.

(6) Unpublished data made available by Chevron Research.

(7) Cold Weather Driveability Performance of 1975-1981 Model Cars, A.M. Horowitz & M.S. Stawnychy, Mobil R&D, SAE Technical Paper #821203, 1982.

(8) Oil and Gas Journal, September 21, 1981, p. 71.

SECTION 4

DETAILED RESULTS AND METHODOLOGIES

Material presented in this section provides the supporting detail for results derived from the study of impacts of lowering the allowable vapor pressure of summer gasolines in the State of California. Order of presentation parallels that of Section 2. Where appropriate, details of methodologies and calculations are also presented.

4.1 HYDROCARBON EMISSIONS IMPACTS

Restricting the vapor pressure of summer gasoline is one avenue toward reduced hydrocarbon emissions. Thus, a prime objective of this study is the assessment of changes in emissions. These changes include vehicular, as well as non-vehicular, source effects. Details of assessment methods and results are presented in the following subsections.

Two major studies by which vehicular emissions were related to gasoline volatility were made in the late 1960's to late 1970's using test vehicles that, in the aggregate, represented model years 1968 through 1977.[1] [2] [3] In each of these studies, RVP and other volatility characteristics were varied systematically to allow analysis of the several relevant volatility variables. Later studies have focused upon the effects of fuel volatility when alcohols are blended with gasoline. However, the use of data from fuels that contained alcohol is questionable for the following reasons.

1) Compared with straight gasoline, azeotropic behavior of alcohol-gasoline mixtures changes both the quantity and the vapor composition of material evaporated during distillation and during vaporization in the fuel system.

2) Alcohol behaves quite differently from light hydrocarbons with regard to adsorption/ description characteristics and thus to behavior in evaporative-loss-control canisters.

Given these considerations, the data base was limited to fuels that did not contain alcohol. Two principal data sources, therefore, remain:

1) Emissions effect on pre-control vehicles were estimated from relationships developed by Wade, et al[4] using data from the series of experiments [1] & [2] referenced above. This work was done by the U.S. Bureau of Mines using a total of thirty-one 1968-70 vehicles, and

2) Effects on post-control vehicles were estimated from relationships developed using data from experiments sponsored by API, reference[3]. Model years 1974 through 1977 were represented in eight vehicles used for the tests.

The data are notably lacking in information directly related to 1978 and later model year cars and therefore extrapolation of the data to late-model and future production is put in question. With respect to exhaust emissions, however, two considerations are relevant:

1) For catalytic and non-catalytic systems, respectively, basic engine combustion and exhaust hydrocarbon control concepts will not have changed markedly from those represented in the late 1970's test vehicles, and

2) Throughout the period of the late 1960's through the late 1970's, during which time engines and hydrocarbon control were changed markedly, patterns of sensitivity to fuel volatility remained relatively consistent.

On this evidence, it appears that extrapolation of existing data will provide useful and credible estimates of future expectations for volatility effects on exhaust emissions.

With regard to evaporative emissions, data were not found that would be directly applicable to gasolines used in 1980 and later (i.e. 2-gram-control-level) vehicles. Moreover, emissions control requirements, control technology, and fuel system design which impacts evaporative losses (e.g., fuel injection) all have changed substantially from those that prevailed in systems for which the bulk of experimental data are available. Therefore, use of relationships established in the two major studies of the 1960's and 1970's is speculative.

Beyond the two major studies, the data are limited to information from a study that involved three 1978-79 vehicles.[1] An approach to projecting effects on evaporative emissions has, therefore, been chosen wherein estimates are based on the relationships developed in the two major studies (referenced earlier) and where those estimates are qualified to reflect the evidence found in work with the three 1978-79 model vehicles.(5)

The data base as described above provides the following equations that relate fuel volatility to emissions:

EXHAUST EMISSIONS:

For Non-catalyst Vehicles

$$HC_A = 3.166-0.08[RVP + 0.8(\%160)] + 0.00148[RVP + 0.8(\%160)]^2$$

(at a value of approximately 27 for [RVP + 0.8(%160)], HCA at a minimum)

For Catalyst Equipped Vehicles

$$HC_A = 1.544-0.185[RVP + 0.13(\%160)] + 0.00789[RVP + 0.13(\%160)]^2$$

(at a value of approximately 11.7 for [RVP + 0.13(%160)], HCA at a minimum)

Where, HC_A = exhaust hydrocarbon in grams per mile
RVP = Reid Vapor Pressure, psi, and
%160 = percent distilled at 160°F

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[1]Evaporative loss control level for these vehicles was 6.0 grams.

EVAPORATIVE EMISSIONS

For Pre-Control Vehicles

Total Evaporative, $HC_E = 0.0692 \times RVP^2/(14.7-1.01\ RVP) + 0.0719(\%160)-0.5317$

For '70-'77 Vehicles, Category A Control[1]

Hot soak loss, $HC_E = \log_e^{-1}[0.062(RVP + 0.6(\%160))-1.132]$

Diurnal loss, $HC_E = \log_e^{-1}(0.546\ RVP-8.182)$

For '70-'77 Vehicles, Category B Control[2]

Hot soak loss, $HC_E = 0.061[RVP + 0.2(\%160)]-0.403$

Diurnal loss, $HC_E = \log_e^{-1}(0.583\ RVP-8.219)$

Where, HC_E = evaporative loss hydrocarbon in grams per mile, RVP and %160 are as previously defined.

Note: For pre-control vehicles the calculation yields total evaporative emissions for an assumed 95°F Los Angeles day. For controlled vehicles the calculation yields predicted SHED values that do not necessarily reflect sensitivity to ambient temperature at the different RVP levels. Evaporative loss data at elevated ambient temperatures are needed to resolve uncertainty in this area.

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[1] Category A Control denotes canister control of tank (diurnal) losses only.

[2] Category B Control denotes canister control of both tank and carburetor (hot soak) losses.

For '78-'79 Vehicles

Evaporative losses are shown to be essentially independent of fuel volatility within the range approximately 5-10 RVP.

The relationships given above were used, as applicable, to calculate exhaust and evaporative emission rates for each of the vehicle classes as designated.[1] Calculations were made assuming gasoline characteristics projected by results from the industry-level model of California refining for each of the RVP levels in the years 1985 and 1990.

Comparison of model-predicted distillation characteristics to those for survey samples for California summer gasoline indicates a model bias. Systematic review of blending data and yields for gasoline components does not provide an explanation for this bias. There is no reason, however, to expect a change in distillation characteristics at similar vapor pressure limits. Therefore, model-predicted values for percent distilled at 160°F and for 50 percent temperatures have been adjusted by a constant to force results at 9 RVP to match the arithmetic average of data from survey results. Model results and adjusted results are shown in Table 4-1.

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[1] Calculations for the '78-79 vehicles were unnecessary inasmuch as the data for those vehicles show no measurable sensitivity to RVP change within the RVP range of interest.

TABLE 4-1

ADJUSTMENT OF MODEL-PREDICTED DISTILLATION CHARACTERISTICS

			% @ 160°F		50% Temp., °F	
Year	Grade	RVP	Predicted	W/Bias	Predicted	W/Bias
1985	Leaded Regular	8.7	33.3	24.3	196	219
		7.7	32.5	23.5	197	220
		6.7	30.4	21.4	199	222
		5.7	26.0	17.0	200	223
1985	Unleaded Regular	8.7	31.9	21.9	198	228
		7.7	29.6	19.6	201	232
		6.7	27.0	17.0	207	238
		5.7	21.8	11.8	215	246
1985	Unleaded Premium	8.7	29.6	17.6	211	232
		7.7	28.6	16.6	213	234
		6.7	28.2	16.2	217	238
		5.7	22.8	10.8	219	240
1990	Leaded Regular	8.7	35.0	24.0	193	217
		7.7	32.5	21.5	195	219
		6.7	30.8	19.8	196	220
		5.7	24.5	13.5	210	234
1990	Unleaded Regular	8.7	27.9	21.9	204	228
		7.7	27.3	21.3	207	231
		6.7	26.3	20.3	209	233
		5.7	21.8	15.8	215	239
1990	Unleaded Premium	8.7	27.9	17.9	215	232
		7.7	24.8	14.8	220	237
		6.7	23.3	13.3	219	236
		5.7	22.9	12.9	219	236

The emission rates calculated using the values from Table 4-1 were used to obtain emission adjustment factors which would relate emissions at each reduced volatility level to the emissions projected for the corresponding 9 RVP base fuel. Except for their use in calculating the adjustment factors, the emission rates have no significance in the study and are therefore unreported.

Emission adjustment factors were then used to adjust exhaust and evaporation emissions projected by ARB. The emissions data were provided in the form of computer projections dated March 13, 1982 and entitled "Predicted California Vehicle Emissions". The projections as provided included the years 1978 and 1990. Projections for 1985 and 1990 are included in Appendix H.

The methodology for developing these projections is described in an ARB publication(6) and its supplements.(7)(8) The data and methods used in making the estimates obviously become part of the basis for the work reported here. These emissions data are total hydrocarbon emissions. For the purposes of the study, emissions of reactive organic gases were requested. Total hydrocarbon emissions were, therefore, converted to reactive organic emissions using factors developed by ARB.(9) The factors used were:

Gasoline Exhaust - Catalytic Control	0.935
Gasoline Exhaust - Non-Catalytic Control	0.967
Gasoline Evaporation	1.000

4.1.1 Vehicle Exhaust Emissions

Adjustment factors were calculated for two classes of vehicles--those with catalysts and those without. The latter, non-catalyst vehicles, include both pre-control and post-control vehicles that employ only engine modifications for exhaust emissions control. Catalyst vehicles include those using unleaded regular and unleaded premium grades of gasoline. The factors are presented in Table 4-2.

The general character of the interactive RVP and %160 influences appears to have been well established in the behavior of vehicles produced through the late '70's. However, data are inadequate to define the combination of RVP and %160 that will result in minimal exhaust emissions for late model cars.

In estimating emissions impacts, it was recognized that the 50 percent distillation points projected by LP model results for the 1985/90 fuels were somewhat lower than is typical of current fuels and there was concern for the effect that an assumed higher 50 percent temperatures would have on estimated emissions. Accordingly, calculations were made using distillation values more nearly corresponding to 1980 fuels. Re-calculation resulted in no substantial effect of the revised 50 percent data and therefore the factors were allowed to stand as originally calculated.

The estimated exhaust emissions for different fuel volatilities are listed in Table 4-3. In estimating emissions for catalyst-equipped vehicles, the adjustment factors for unleaded regular and unleaded premium grades were weighted by the forecasted volumes of these gasoline grades.

Volumes forecast for 1985 and 1990 are:

Year	Barrels/Calendar Day Unleaded Regular	Unleaded Premium
1985	385,000	155,000
1990	393,000	196,000

TABLE 4-2

EXHAUST EMISSIONS ADJUSTMENT FACTORS[1]

Year	Fuel RVP	Non-Catalyst Cars Leaded Gasoline		Catalyst Cars Unleaded		Catalyst Cars Unleaded Premium	
		(2)	(3)	(2)	(3)	(2)	(3)
1985	9	1.00	1.00	1.00	1.00	1.00	1.00
	8	0.98	1.00	0.98	1.04	0.99	1.05
	7	0.96	1.00	1.02	1.13	1.02	1.14
	6	0.95	1.04	1.15	1.35	1.15	1.35
1990	9	1.00	1.00	1.00	1.00	1.00	1.00
	8	0.97	1.03	1.00	1.03	1.00	1.07
	7	0.95	1.05	1.04	1.10	1.06	1.18
	6	0.94	1.07	1.17	1.27	1.15	1.32

[1] Two-place accuracy is shown to present the trends that result from the evaluations employed even though such accuracy cannot be defended.
(2)Using model-predicted volatilities.
(3)Using adjusted volatilities.

TABLE 4-3

ESTIMATED CALIFORNIA VEHICLE EXHAUST EMISSIONS

(Emissions of Reactive Organic Gases in Short Tons Per Day)

Sheet 1 of 2

Using Model-Predicted Volatility Results

		Light-Duty Passenger		Light-Duty Trucks		Medium-Duty Trucks				
Year	Fuel RVP	Cat	Non-Cat	Cat	Non-Cat	Cat	Non-Cat	Heavy-Duty Trucks	Motor-cycles	Total
1985	9	413	113	79	52	22	27	51	11	768
	8	406	111	77	52	21	27	50	10	754
	7	421	109	80	50	22	26	49	10	767
	6	475	107	90	50	25	26	49	10	832
1990	9	468	24	97	22	29	12	48	10	710
	8	468	24	97	21	29	12	46	10	707
	7	489	23	102	21	30	11	46	10	732
	6	544	23	113	20	34	11	45	10	800

TABLE 4-3

ESTIMATED CALIFORNIA VEHICLE EXHAUST EMISSIONS

(Emissions of Reactive Organic Gases in Short Tons Per Day)

Sheet 2 of 2

Using Adjusted Volatility Results

Year	Fuel RVP	Light-Duty Passenger Cat	Light-Duty Passenger Non-Cat	Light-Duty Trucks Cat	Light-Duty Trucks Non-Cat	Medium-Duty Trucks Cat	Medium-Duty Trucks Non-Cat	Heavy-Duty Trucks	Motor-cycles	Total
1985	9	413	113	79	52	22	27	51	11	768
	8	430	113	82	52	23	27	51	11	789
	7	467	113	89	52	25	27	51	11	835
	6	558	118	107	54	30	28	53	11	959
1990	9	468	24	97	22	29	12	48	10	710
	8	487	25	101	23	30	12	49	10	737
	7	529	25	110	23	33	13	50	10	793
	6	604	26	125	24	37	13	51	11	891

Heavy duty trucks and motorcycles were assumed to use leaded gasoline only.

Reduction of fuel volatility outside the range for which vehicles currently are designed would almost certainly have some effect on CO and NO_x emissions but the limited scope of this study precluded investigation and estimation of those effects. Directionally, CO emissions may be expected to increase with use of lower RVP fuel at the lower ambient temperatures that would be encountered. Specific attention to the question of RVP impact on CO emissions probably is warranted in case further consideration is given to volatility reduction.

4.1.2 Vehicular Evaporative Emissions

Factors were calculated for three categories of vehicles: (1) pre-control, (2) Category "A" evaporative control defined as including those systems employing canister storage only for fuel tank or diurnal loss, and (3) Category "B" defined as including those vehicles equipped with canister storage for both diurnal and hot soak losses. Evaporative emission factors are shown in Table 4-4.

These factors were averaged and weighted using predicted gasoline grade volumes to arrive at a weighted average factor for each future case. This weighted average factor was multiplied times total vehicle evaporative emissions as shown in the ARB projections in order to estimate emissions at reduced RVP limits. This approach was used

TABLE 4-4

EVAPORATIVE EMISSIONS ADJUSTMENT FACTORS[a]

Sheet 1 of 2

Using Model-Predicted Volatility Results

Year	Fuel RVP	--Pre-Control-- Vehicles: Leaded Gasoline	--Pre-Control-- Vehicles: Unleaded	--Pre-Control-- Vehicles: Unleaded Premium	--Post-Control-- Vehicles[b]: Leaded Gasoline "A"	Leaded Gasoline "B"	Unleaded "A"	Unleaded "B"	Unleaded Premium "A"	Unleaded Premium "B"
1985	9	1.00			1.00	1.00	1.00	1.00	1.00	1.00
	8	.87			.91	.85	.86	.81	.90	.83
	7	.74			.79	.68	.73	.62	.83	.68
	6	.58			.63	.47	.56	.39	.64	.43
1990	9	1.00			1.00	1.00	1.00	1.00	1.00	1.00
	8	.86			.85	.82	.91	.83	.83	.77
	7	.74			.75	.66	.82	.66	.74	.59
	6	.55			.56	.42	.65	.43	.68	.45

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[a] Two-place accuracy is doubtful for the values in this table but the second decimal is retained to better enable visualization of the trends that result from application of the correlations that were used.

[b] A limited amount of data obtained in tests with 1978 and 1979 model vehicles would indicate no measurable effect on evaporative emissions in reducing fuel volatility within the range of 10 to 5 RVP. The data base is judged inadequate to extrapolate those findings to the post-'79 car population; however, the indication of reduced sensitivity to RVP in post-'79 production is positive. The factors given here should therefore be considered only as downside limits (i.e., maximum effects) and should not be considered as effects to be anticipated for the car population of the next decade.

TABLE 4-4

EVAPORATIVE EMISSIONS ADJUSTMENT FACTORS[a]

Sheet 2 of 2

Using Adjusted Volatility Results

Year	Fuel RVP	Pre-Control Vehicles: Leaded Gasoline	Pre-Control Vehicles: Unleaded	Pre-Control Vehicles: Unleaded Premium	Post-Control Vehicles[b]: Leaded Gasoline "A"	Post-Control Vehicles[b]: Leaded Gasoline "B"	Post-Control Vehicles[b]: Unleaded "A"	Post-Control Vehicles[b]: Unleaded "B"	Post-Control Vehicles[b]: Unleaded Premium "A"	Post-Control Vehicles[b]: Unleaded Premium "B"
1985	9	1.00			1.00	1.00	1.00	1.00	1.00	1.00
	8	0.83			.90	.81	.85	.76	.90	.76
	7	0.67			.78	.60	.73	.52	.82	.56
	6	0.45			.62	.34	.56	.22	.63	.22
1990	9	1.00			1.00	1.00	1.00	1.00	1.00	1.00
	8	0.77			.85	.76	.91	.80	.83	.70
	7	0.62			.75	.56	.82	.61	.73	.47
	6	0.33			.55	.25	.65	.33	.68	.28

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[a] Two-place accuracy is doubtful for the values in this table but the second decimal is retained to better enable visualization of the trends that result from application of the correlations that were used.

[b] A limited amount of data obtained in tests with 1978 and 1979 model vehicles would indicate no measurable effect on evaporative emissions in reducing fuel volatility within the range of 10 to 5 RVP. The data base is judged inadequate to extrapolate those findings to the post-'79 car population; however, the indication of reduced sensitivity to RVP in post-'79 production is positive. The factors given here should therefore be considered only as downside limits (i.e., maximum effects) and should not be considered as effects to be anticipated for the car population of the next decade.

because there was not a complete set of data for defining the number of vehicles using each type of emission control. Arithmetic averages were computed for the following groups:

1) Leaded gasoline: pre-control vehicles; post-control, Category "A"; and post-control, Category "B".

2) Unleaded gasoline: post-control vehicle, Category "A" and Category "B".

3) Unleaded premium gasoline: post-control, Category "A" and Category "B".

These group averages were then weighted using fore-casted refinery output volumes to calculate an overall weighted average for a given RVP case for a given year. This overall factor was multiplied times ARB predicted fuel tank (diurnal) and hot soak (carburetor) emissions and added to ARB predicted crankcase emissions to estimate total evap-orative emissions. Table 4-5 shows group average factors, weighting values and calculated evaporative emissions, all of which are considered to be reactive organics.[1]

As would be expected, the results show that vehicle evaporative emissions decrease with reduced fuel volatility.[2] The decrease is much more significant in 1985 than in 1990. The effect is attributed to a larger population of vehicles having 2 gram control level and a smaller population having older, less effective evaporative controls in 1990. Even

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[1] An example calculation is given at the end of this sub-section.

[2] See footnotes in Table 4-4.

TABLE 4-5

ESTIMATED CALIFORNIA VEHICLE EVAPORATIVE EMISSIONS

Sheet 1 of 2

Using Model Predicted Volatility Results

		Averaged & Weighted Factors				Emissions, short ton/day		
Year	Fuel RVP	Leaded	Unleaded	Unleaded Premium	Weighted Average	Diurnal & Hot Soak	Crank Case	Total
1985	9	1.00	1.00	1.00	1.00 (1)	270	2	272
	8	0.88	0.83	0.87	0.85 (1)	230	2	232
	7	0.74	0.67	0.75	0.71 (1)	191	2	193
	6	0.56	0.47	0.53	0.51 (1)	138	2	140
1990	9	1.00	1.00	1.00	1.00 (2)	139	0	139
	8	0.84	0.87	0.80	0.85 (2)	118	0	118
	7	0.72	0.74	0.67	0.71 (2)	100	0	100
	6	0.51	0.54	0.57	0.54 (2)	75	0	75

(1) Weighted on the basis of the following gasoline volumes: Leaded - 205,000 B/CD, Unleaded Regular - 385,000 B/CD and Unleaded Premium - 155,000 B/CD

(2) Weighted on the basis of the following volumes: Leaded - 121,000 B/CD, Unleaded Regular - 393,000 B/CD and Unleaded Premium - 196,000 B/CD

TABLE 4-5

ESTIMATED CALIFORNIA VEHICLE EVAPORATIVE EMISSIONS

Sheet 2 of 2

Using Adjusted Volatility Results

		Averaged & Weighted Factors				Emissions, short ton/day		
Year	Fuel RVP	Leaded	Unleaded	Unleaded Premium	Weighted Average	Diurnal & Hot Soak	Crank Case	Total
1985	9	1.00	1.00	1.00	1.00 (1)	270	2	272
	8	0.85	0.81	0.83	0.83 (1)	224	2	226
	7	0.68	0.63	0.69	0.66 (1)	178	2	180
	6	0.47	0.39	0.43	0.42 (1)	113	2	115
1990	9	1.00	1.00	1.00	1.00 (2)	139	0	139
	8	0.79	0.86	0.77	0.82 (2)	114	0	114
	7	0.64	0.72	0.60	0.67 (2)	93	0	93
	6	0.38	0.49	0.48	0.47 (2)	65	0	65

(1) Weighted on the basis of the following gasoline volumes: Leaded - 205,000 B/CD, Unleaded Regular - 385,000 B/CD and Unleaded Premium - 155,000 B/CD

(2) Weighted on the basis of the following volumes: Leaded - 121,000 B/CD, Unleaded Regular - 393,000 B/CD and Unleaded Premium - 196,000 B/CD

without a fuel volatility reduction, evaporative losses from vehicles in 1990 are predicted to be about 50 percent of 1985 losses. Since limited recent test data indicates the possibility that post-control vehicles would show no change in evaporative losses with decreased vapor pressure, the estimates in Table 4-5 should be viewed as maximum benefit values. Changing post-control vehicle factors in Table 4-4 to a constant 1.00 produces weighted average factors that vary no more than five percent from the base factors. Under such an assumption, evaporative emissions estimates decrease by no more than 12 short tons per day for 1985 and less than six short tons per day in 1990.

An example calculation for 1985, 8 RVP follows:

1) Average the evaporative emission adjustment factor from Table 4-3 for each grade of gasoline

   Leaded = (0.87+0.91+0.85) - 3 = 0.877
   Unleaded = (0.86+0.81) - 2 = 0.835
   Unleaded Prem. = (0.90+0.83) - 2 = 0.865

2) Calculate a weighted average

   Total gasoline volume = 745,000 BPD
   Weighted Average = [(0.877)(205,000) + (0.835)(385,000) + (0.865)(155,000)] - 745,000 = 0.852

3) Calculate diurnal and hot soak emission

   = 0.852(270) = 230 ton/day

4) Calculate total evaporative emission by adding crankcase emission

   230 + 2 = 232 ton/day

4.1.3 Non-Vehicular Emissions

Sources of non-vehicular emissions comprise gasoline storage and distribution facilities beginning at product gasoline storage in the refinery, continuing with transportation by tank truck or tank car, storage in bulk plants or terminals and culminating in refueling of the vehicle. Hydrocarbon emissions from these sources result from breathing, working, spillage and from diffusional effects related to vapor pressure.

An existing hydrocarbons emission inventory obtained from ARB was used as a basis for estimating the effects of fuel volatility on hydrocarbon emissions from non-vehicular sources. The storage distribution network was characterized in terms of the equipment involved, emission controls that would be in place and the effect of vapor pressure on emissions from the various operations involved in storage and distribution. The effect of vapor pressure was correlated in terms of adjustment factors which could be applied to the emissions inventory in order to predict emissions at reduced vapor pressure.

4.1.3.1 Emission Inventory

The basis for the work was a series of computerized projections[1] done by ARB for the years 1979, 1983 and 1987 entitled "Emissions Data System/Gasoline-Evap". These reports give emissions by process and activity for each air

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[1] Computer printouts were dated December 21, 1982, December 22, 1982 and December 26, 1982, respectively.

basin in California. Process categories include broad areas of hydrocarbon emissions such as tanks, tank cars and trucks, marine vessels, vehicle refueling and off-road motor vehicles. Activity categories give additional breakdown of emissions within the process categories and include such activities as petroleum refining, bulk plants, and service stations. For the purpose of the work performed here, emissions for on-road motor vehicles were extracted from the emissions inventory since that type of emissions is considered earlier in subsections 4.1.1 and 4.1.2.

Since the object of this work was to estimate emissions in 1985 and 1990, the existing inventory had to be translated from 1983 and 1987 to the years of interest. Fortunately, hydrocarbon emissions in 1983 and 1987 were nearly constant once emissions from on-road motor vehicles were extracted. Emissions from non-vehicular sources were projected to be 113 tons/day in 1983 and 115 tons/day in 1987 for the entire state. The 1983 inventory was then assumed to be applicable to 1985 and the 1987 inventory was assumed to be applicable to 1990.

4.1.3.2 Liquid Storage

Two types of storage are used for storing relatively large volumes of gasoline - floating-roof tanks and fixed cone-roof tanks equipped with vapor recovery facilities. Gasoline is also stored in drum-type storage containers in service stations and small storage facilities. Hydrocarbon emissions occur through breathing and working.

This study assumes that floating-roof storage is used for large volume storage requirements such as petroleum refinery product storage. Cone-roof storage tanks are assumed to be used in other storage applications.

AP-42[10] gives correlations for predicting emissions from both types of storage. The effect of vapor pressure in these correlations, usually expressed as true vapor-pressure, was analyzed in order to determine adjustment factors for lower volatility gasoline products. In floating-roof tanks, the effect of vapor pressure on breathing losses is related by the following expression:

$$\frac{\left(\frac{p}{14.7}\right)}{\left[1 + \left(1 - \frac{p}{14.7}\right)0.5\right]^2}$$

Where p is the true vapor pressure, in psi, at a given temperature corresponding to a given Reid vapor pressure. In all work performed, the temperature was assumed to be 70°F. Using this expression, adjustment factors for breathing losses from floating-roof tanks were determined as follows:

RVP	Adjustment Factor
9	1.0
8	0.842
7	0.735
6	0.593

In addition to breathing losses, floating-roof tanks also experience working losses. However, these are small by comparison and for purposes of adjusting the emissions inventory, the above factors were used.

In cone-roof tanks breathing losses are related to true vapor pressure by the following expression.

$$\frac{p}{14.7 - p}$$

Working losses are also a function of true vapor pressure. The adjustment factors that were determined for breathing and working losses are summarized below.

RVP	Breathing Adjustment Factor	Working Adjustment Factor
9	1.000	1.000
8	0.867	0.873
7	0.799	0.782
6	0.656	0.655

Since the factors for breathing and working were so similar, the factors for breathing losses were used in adjusting the emission inventory.

4.1.3.3 Loading Losses

Loading losses are applicable to tank car, truck and marine operations. Emission factors given in AP-42 show that loading losses are a direct linear function of true vapor pressure. Therefore, adjustment factors to the ARB predicted hydrocarbon emissions from tank cars, trucks, and marine vessels were calculated by converting RVP to vapor pressure at 70°F and divided by the vapor pressure corresponding to 9 RVP. The adjustment factors are summarized as follows:

RVP	Adjustment Factor
9	1.000
8	0.873
7	0.782
6	0.655

4.1.3.4 Vehicle Refueling

Two sets of adjustment factors were calculated for estimating emissions from vehicle refueling: one set for estimating emissions from service station operation, and one set for all other refueling operations. Service station operations were assumed to employ Stage II controls while all other refueling operations were assumed to not require such controls. Stage II controls recover displaced gasoline vapors from vehicle fuel tanks during filling operations.

For service station operations, it was determined that emissions as predicted by ARB resulted equally from loading losses (described in 4.1.3.3) and from spillage. Fuel volatility has no effect upon spillage. Thus, calculated adjustment factors reflecting this weighting of loading losses and spillage are as follows:

RVP	Adjustment Factors
9	1.000
8	0.937
7	0.891
6	0.828

Where Stage II controls are not involved, loading losses dominate spillage. Investigations indicated that loading loss resulted in about 90 percent of the emissions from vehicle refueling whereas spillage accounted for 10 percent. Again, spillage is unrelated to fuel volatility. Consequently, by weighting loading losses to account for 90 percent of vehicle refueling emissions and spillage for 10 percent, the following adjustment factors were determined:

RVP	Adjustment Factors
9	1.000
8	0.886
7	0.804
6	0.690

4.1.3.5 Impact on Non-Vehicular Emissions

Estimated non-vehicular hydrocarbon emissions at reduced gasoline volatilities are summarized in Table 4-6. These emissions were treated as reactive organic gases. Total emissions from all process and activity categories (except on-road motor vehicles) are shown for each air basin and the total state.

Emissions in 1985 and 1990 are nearly the same, indicating there are no other significant changes affecting hydrocarbon emissions. This implies that there are no major additions to storage, increases or decreases in gasoline volumes, or implementation of hydrocarbon emission controls. The ARB hydrocarbon emission inventory for the same sources for 1979 show significantly higher emissions than for 1983. The reduction in emissions from 1979 to 1983 was approximately 40 percent. This reduction in emissions is attributed to implementation of Stage II controls at service stations in major air basins.

less than six tons per day. Under such an assumption, the net cumulative reduction (using adjusted volatility results) for a 6 RVP limit would be -145 and -138 tons per day for 1985 and 1990, respectively. Even with a limit of 8 RVP the net emissions are slightly increased using the emissions based on adjusted volatility results.

4.1.5 Refinery Process Emissions

Refinery changes to produce lower volatility fuel result in material balance changes and process through-put changes that could affect refinery process emissions. For example, low molecular weight hydrocarbons are backed out of gasoline and additional coke production and sulfur recovery occur. In addition, greater quantities of fuel are used in combustion operations.

The purpose of the work reported in this section is to address changes in refinery process emissions that might occur as a consequence of producing lower volatility fuels.

4.1.5.1 Analytical Approach

The approach taken considered only significant changes that could result in major contributions to pollutant emissions. These emissions include particulates, hydrocarbons, carbon monoxide (CO), sulfur dioxide (SO_2), and nitrogen oxides (NO_x). Major areas where significant changes in pollutant emissions could occur were determined to be catalytic cracking, sulfur recovery, fuel combustion and coke handling. Changes in hydrocarbon emissions from refinery storage tanks were excluded since these emissions are addressed in subsection 4.1.3.5.

Emissions factors were addressed broadly since the characterization had to represent all California refineries. Source material used to establish emission criteria include AP-42[10], BAAQMD Rules and Regulations[11], and SCAQMD Rules and Regulations[12]. In addition, work from a recent refinery environmental impact report was used to estimate some emission criteria that was not directly available from any of the other source material.

Catalytic cracking units in California refineries would be expected to have electrostatic precipitators and CO boilers. AP-42 suggests using emission factors of 45 lb/10^3 barrels of fresh feed for particulates and 71 lb/10^3 barrel of fresh feed for nitrogen oxide. Carbon monoxide and hydrocarbons are negligible downstream of CO boilers. SO_2 emissions from a catalytic cracking regenerator are available directly from the LP runs performed in this study.

Refineries in California would have highly efficient tailgas treating units. Recovery of additional sulfur production can be assumed to be 99.9 percent effective, leaving 0.1 percent to be emitted as SO_2.

Both refinery fuel gas combustion and liquid fuel oil combustion must be addressed because LP results showed that fuel oil combustion decreased and refinery fuel gas combustion increased as a consequence of changes to produce reduced volatility gasolines. Emission factors for gas and fuel oil combustion were derived from AP-42 and converted to a billion (10^9) BTU heating value basis. Sulfur dioxide emissions from fuel gas combustion were determined on the basis of the gas containing 0.1 grain/scf H2S, which is the new source standard. SO_2 emissions from fuel oil combustion were evaluated on the basis of an average fuel sulfur content of 0.347 weight percent. This value was derived from the LP results and represents a mix of low and medium sulfur No. 6 fuel oil. Emission factors used in this work are summarized in Table 4-8.

Coke handling results in fugitive particulate emissions. Other coking related emissions, such as sulfur dioxide and combustion emissions are accounted for in the sulfur recovery and fuel combustion emissions. Fugitive emissions related to coke handling are based on a recent refinery environmental impact report concerning a 600 ton/day coker addition. The project included controls such as sprays, baghouses and buildings to enclose coke storage that would probably be typical of California refineries today. The fugitive emissions from this project were 3.63 lb/hr. Coke handling particulate emissions in this work are ratioed from this particular refinery basis.

4.1.5.2 Changes in Refinery Emissions

Important refinery unit through-put and material balance changes are shown in Table 4-9. The changes shown are those judged most likely to affect process emissions. The data shown in this table have been extracted from LP model results and assume that rejected low-boiling hydrocarbons displace fuel oil in the industrial energy supply.

TABLE 4-8

FUEL COMBUSTION EMISSION FACTORS

Pollutant	Emission Factor, lb/10^9 BTU Fuel Gas Combustion	Emission Factor, lb/10^9 BTU Fuel Oil Combustion
Particulate	10.5	39
SO_2	20.4	386
CO	17.9	35.5
Hydrocarbon	-	7
NO_x	174	425

TABLE 4-9

REFINERY CHANGES AFFECTING PROCESS EMISSIONS

		INCREASED THROUGHPUT, PRODUCTION OR USE					
		Cat Cracking		Sulfur	Coking	Fuels	
Year	RVP	Thruput 10^3 B/D	SO_2 ST/D	Recovered Sulfur ST/D	Coke ST/D	Gas 10^9 BTU/Day	Oil 10^9 BTU/Day
1985	9[a]	408.289	75	1144	11275	432.848	237.212
	8	7.677	0	10	227	64.946	-54.215
	7	21.116	-1	30	468	120.846	-96.409
	6	32.903	-2	42	933	225.429	-186.997
1990	9[a]	384.271	89	1654	14352	402.288	294.674
	8	6.615	0	7	223	62.807	-49.119
	7	9.538	-1	26	441	129.158	-95.544
	6A[b]	24.875	-1	47	893	245.868	-192.142
	6B[b]	0.273	0	42	881	202.067	-166.311

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[a] 9 RVP cases show base throughput or production quantities. All other cases show increase over 9 RVP case.

[b] 6A is 1500 ppm sulfur in gasoline products. 6B is 400 ppm sulfur in gasoline products.

Most LP results in Table 4-9 are based upon 1500 ppm sulfur content for gasoline products. Two 6-RVP cases in 1990 are shown. One represents 1500 ppm sulfur content; the second, Case 6B, represents 400 ppm sulfur content. With the exception of catalytic cracking, gasoline sulfur level does not change the results shown in a manner that would significantly effect process emission estimates. The 1990 low sulfur case (6B) indicates the catalytic cracking throughput and regenerator SO_2 production will not change. In calculating process emissions from catalytic cracking, the other fuel volatility cases were adjusted to reflect the impact of lowsulfur gasoline products. The current limit for gasoline sulfur content is 300 ppm. While measurable, the effect of changing gasoline sulfur content from 1500 ppm to 400 ppm is small and suggests that there is no significant effect for lowering to 300 ppm. Use of the 1500-ppm results represent a worst-case situation.

Pollutant emission changes were determined using the data from Table 4-9 and emission factors described in subsection 4.1.5.1. The changes are summarized in Table 4-9. Emission changes from catalytic cracking, sulfur recovery and coke handling were inconsequential (less than 0.1 ton/day). The only consequential changes were those that resulted from fuel combustion. Virtually all of the changes shown in Table 4-10 are the result of fuel combustion emission effects. The table shows that process emissions decreased. The reason is that low-sulfur and medium-sulfur fuel oil is backed out of refinery fuel and light hydrocarbons (being backed out of gasoline) are being burned instead. Because fuel gas combustion results in lower pollutant emissions than does fuel oil combustion (see emission factors in Section 3.4.1.3), there is an apparent net reduction in emissions.

TABLE 4-10

INCREMENTAL REFINERY PROCESS EMISSIONS
(Fuel Oil Displaced by Rejected Hydrocarbons)

		Incremental Emissions, ton/day				
Year	RVP	Particulate	Hydrocarbon	CO	SO_2	NO_x
1985	8	-0.7	-0.2	-0.4	-9.8	-5.9
	7	-1.2	-0.3	-0.6	-17.3	-10.0
	6	-2.4	-0.6	-1.3	-33.7	-20.0
1990	8	-0.6	-0.2	-0.3	-8.8	-5.0
	7	-1.2	-0.3	-0.5	-7.2	-9.1
	6	-2.4	-0.7	-1.2	-34.5	-19.4

Note: Minus indicates emissions reduction.

Industry, however, might not be able to utilize low-boiling hydrocarbons as fuel or might find alternative, more profitable outlets. Should industrial fuel oil use remain constant, incremental process emissions would increase somewhat, as shown in Table 4-11.

TABLE 4-11

INCREMENTAL REFINERY PROCESS EMISSIONS
(Constant Fuel Oil)

		Incremental Emissions, ton/day				
Year	RVP	Particulate	Hydrocarbon	CO	SO_2	NO_x
1985	8	0.1	Nil	0.1	0.1	0.9
	7	0.2	Nil	0.2	0.3	2.1
	6	0.3	Nil	0.3	0.4	3.3
1990	8	0.1	Nil	0.1	0.2	1.2
	7	0.2	Nil	0.3	0.4	2.9
	6	0.4	Nil	0.5	0.6	4.7

4.2 VEHICLE PERFORMANCE

Among the many uncertainties surrounding volatility effects one reasonably firm understanding has emerged: that driveability is influenced by mid-ranged volatility as well as by RVP and by narrowly-defined front-end volatility. It was therefore desirable to examine the changes in 1985-1990 fuels with respect to the mid-range changes that accompany volatility reductions. This was done by estimating, from the fuels quality predictions, two volatility characteristics:

1) Front-end Volatility Index (FEVI), where FEVI = RVP + 0.13(%160°F), and

2) Temperature for 50% evaporated.

From LP model results, these characteristics range as shown in Table 4-12.

For purposes of assessing driveability impacts the FEVI values for all categories of fuels can be considered to decrease within the range between 12 and 7 if volatility were reduced from 9 to 6 RVP. Corresponding fifty percent points would increase by about 5°F to 20°F degrees. Driveability is discussed within the perspective of these ranges of volatility modification.

Driveability studies that are intended to apply to U.S. vehicles typically investigate vapor lock at above-normal temperatures and investigate starting, warm-up, and overall driveability at sub-ambient to normal-ambient temperatures. Vapor lock problems are not normally associated with fuels at the 9 RVP level--and are not at issue in reductions below that level, and therefore for purposes of

TABLE 4-12

RANGE OF VOLATILITY CHARACTERISTICS
(Using Adjusted Volatility Results)

	FEVI				50% Temp., °F			
	9	8	7	6	9	8	7	6
Leaded Regular								
1985	11.8	10.7	9.0	7.9	219	220	222	223
1990	11.9	10.5	9.0	7.5	217	219	220	234
Unleaded Regular								
1985	11.5	10.2	8.9	7.2	229	232	238	246
1990	11.2	10.4	9.3	7.7	230	233	235	241
Unleaded Premium								
1985	10.9	9.8	8.8	7.1	232	234	238	240
1990	11.0	9.6	8.6	7.4	231	236	235	235

from the 1985-1990 cases would shift the 6-RVP curves from the 9-RVP base by about 15 to, possibly, 30 degrees. Comparatively, then, it might be expected that start-and-drive-away demerits would increase possibly 50 to 100 percent between the 9 RVP and corresponding 6 RVP fuels. The average driver's perception of a driveability impairment of this severity would depend upon the level of performance achieved with the base fuel. Using characteristics of the 1985-1990 fuels in connection with findings of the Mobil study, a driveability rating of about 100 demerits would be assigned to the base fuel; ratings for the lower volatility fuels would then be roughly estimated to range between 100 and 200. A recent CRC study predicts only 90-percent customer satisfaction with fuels at 100 demerits rating with severely declining customer acceptance at higher demerit levels.

Data from Chevron[14] support the Mobil data. Chevron data obtained on eight 1973-1976 model cars show engine stalls at both 55°F and 75°F tests to be increased by a factor of about 3 when FEVI is reduced from 11.8 to 8.3. The 11.8 to 8.3 range of FEVI reductions for the Chevron fuels corresponds roughly to the reduction estimated from this study, and therefore comparable effects on driveability are indicated. Thus, an increased, possibly severe[1], frequency of stalls is to be expected with volatility reduced to the extent herein considered.

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[1]Chevron data from tests at 55°F and 75°F show stalls increased from about 10 per 100 starts to between 30 and 50 per 100 starts when FEVI was reduced from 11.8 to 8.3.

4.2.3 Overall Driveability and Emissions Impact

4.2.3.1 Overall Driveability

Work done by CRC using 1980 model cars[2] and unpublished data by Chevron[3] provide the best information for assessing driveability overall. Considering only information from the CRC tests made at intermediate temperatures (40°F to 69°F) volatility is shown related to overall driveability of 1980 cars as a function of T10, T50, and T90 wherein the distillation points are weighted, respectively, at about 0.6, 1.0 and 0.4. Those weightings compare closely with corresponding values, 0.8, 1.0 and 0.3 determined from results of the Mobil work at 45°F.[6]. The weighting values show two things clearly:

1) That <u>both</u> near-front-end volatility (10 percent temperature and RVP) and mid-range volatility (50 percent temperature) are important, and

2) That taken together 10 percent and 50 percent points are dominant as driveability influences.

Direct application of the bulk of available data is uncertain because the fuels that were involved were at RVP levels around 9 RVP and above. However, the data clearly are significant in that they show driveability adversely affected beginning at about the 9-RVP level with fuels having 50 percent points at values projected for the 1985-1990 reduced volatility cases. This is illustrated in Figure 4-1.

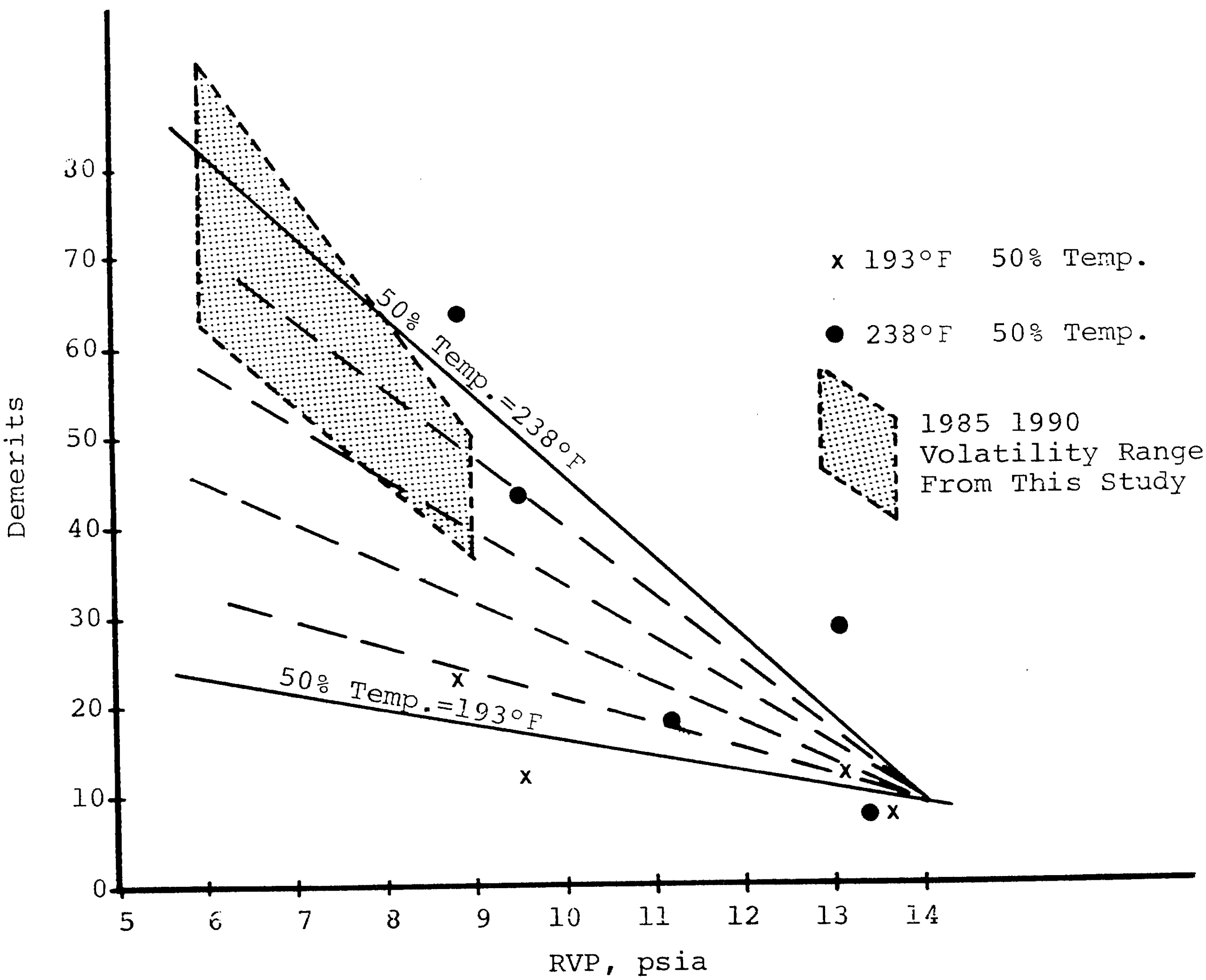

Figure 4-1. 1980 CRC Intermediate Temperature Program
-RVP Effect on Acceleration Stalls-
(At Constant 50% Temp.)

4.2.3.2 Driveability and Emissions Relationships

The emissions adjustment factors that are used in projecting effects on emissions inventory were derived from experience in tests made following the federal emissions test procedure (FTP). The procedure disallows data from tests during which specified engine malfunction occurs, and, in practice, tests typically are aborted upon any other than very minor malfunction. The effect is to exclude from FTP data those measurements that would reflect elevated emissions from significantly malfunctioning engines. For that reason, emissions data from FTP tests will not fully reflect the emissions consequences of malfunctions from fuel related causes.

Considering the relative importance of tailpipe and evaporative emissions, an in-depth investigation of this factor in the overall emissions impact of volatility reduction would be essential to a definitive assessment. However, lacking opportunity for, and information from, a definitive analysis, data from a recent Chevron study provide some guidance. In this study, the emissions data from disallowed tests are compared with the remainder of all tests conducted during the course of a 20 car fleet test of a proprietary product. The disallowed tests involved:

14 occurrences of excessive cranking time
6 occurrences of engine faltering
13 occurrences of engine stall

Eighteen of the twenty cars in the test were included among those that malfunctioned.

Data comparisons showed that hydrocarbon emissions measured roughly twenty-five to thirty-five percent higher in those tests during which a malfunction occurred. Equating this to the real population is not possible but an order-of-magnitude estimate is possible from the data available from the 1975 8-car Chevron work. Results of that work show an increase of between 25 and 35 stalls per 100 starts when fuel volatility was reduced from 11.8 to 8.3 FEVI (as compared with about 11.8 and 7.1 FEVI for the respective and 9-RVP and 6-RVP cases projected for the 1985-1990 California fuels). These data would say that about 35 percent of cold-start trips would result in emissions elevated by possibly an average of 35 percent for an overall increase of 10 percent in emissions during a typical trip from cold-start.

4.2.4 Mileage

The effect of volatility reduction in 1985-1990 fuels would depend more upon engine response to volatility per se than upon any other factor. Specific heat content of the lowest volatility fuel would be from one to two percent higher than that of the corresponding 9-RVP fuel; that fact might suggest a gain in fuel economy. However, fuel economy achieved by current technology engines is highly sensitive to close control over fuel/air mixture ratio--including cylinder-to-cylinder distribution--and to good balance between actual engine response and such factors as choke time/temperature schedules. The operational response of early-'80's vehicles to volatility change is largely unknown and that of later production is not predictable. Actual data are sparse but the data that are available support the expectation that the higher heat content of a typical low volatility fuel is not effectively utilized. Chevron's 8 vehicles test of an 8.3 FEVI fuel against 11.8 FEVI fuel showed a one percent gain in mpg economy but about equal loss in fuel Btu economy. On balance, it appears that there should be expectation neither of significant gain nor of significant loss in fuel economy with volatility reduction. In the area of performance, particularly serious questions about adverse effects on warm-up and acceleration stalls should outweigh consideration for a probably negligible effect on fuel economy.

Finally, it is apparent that the trend in engine design for both emissions control and fuel economy is toward an ever-increasing dependence upon close control of interactive factors that involve fuel characteristics and engine warm-up and acceleration behavior. It appears likely, therefore, that late-model and new engine systems will <u>not</u> provide greater tolerance in fuel characteristics and that significant deviations in fuel characteristics from engine design requirements may incur measurable performance penalty. This assessment of the factors identified above is judgmental but also is supported by views expressed by fuels and engine specialists in discussions entered into for purposes of preparing this report. Recognizing the importance of fuel economy and the criticality of performance in vehicle operations, a more definitive assessment is called for. Fact is, however, that the data essential to more definition assessment are not available and therefore should be acquired if further decisions regarding fuel volatility are to be soundly based.

4.2.5 Safety

Two aspects of impacts on safety warrant attention -- driving safety related primarily to acceleration performance, i.e., hesitation and stalls, and safety related to ignition of fuel tank vapors. Driving safety is not addressed directly in this study but reference to the earlier information covering performance suggests a potential safety problem in this area.

A potential for fuel tank explosion definitely exists with 6-RVP and 7-RVP fuels at temperatures within the range of 30°F downward to 20°F and lower, as shown in the results of calculations following procedures derived from NACA Technical Note 3276 (published 1956)[1]. The risk is probably low at the 7-RVP level of fuel volatility and at the 30°F temperature level. However, it should be recognized that fuels manufactured to the 6-RVP or 7-RVP level will generally fall below the specified RVP limit and in some cases may be well below that value. Moreover, unusual conditions can increase the risk of encountering an ignitable air/fuel mixture beyond normal expectations. For example, near-exhaustion of liquid fuel can appreciably affect the explosivity of vapor above the liquid in the tank. This would be particularly true if the fuel temperature were elevated during daytime summer driving and allowed to cool overnight at an abnormally low temperature.

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[1] For the method of calculation see Appendix G.

Hydrocarbon concentration in the air/fuel mixture at equilibrium over fuel at varied temperature is shown in Figure 4-2. Hydrocarbon concentrations below ten percent should be considered dangerous and an explosive condition indicated below nine percent. The rich flammability limit for gasoline vapor is given as 7.6 volume percent by NFPA, but this value applies to the vapor mixture of full-boiling-range gasolines. Calculated values for the flammability limits of the equilibrium vapor mixture provide a more reliable guide to risk of fuel tank vapor ignition and should be used here. The principal conclusion is that fuels within the range of the lower volatility levels being studied, under conditions that logically could be encountered, will generate a potential for fuel tank vapor ignition. A detailed assessment of the relative risk at various RVP levels and the identification of exposure factors, e.g. time, temperature, location, are beyond the scope of this study. As a convenient source of reference, however, calculated values for hydrocarbon concentrations and flammability limits as determined for this study are included in Appendix G.

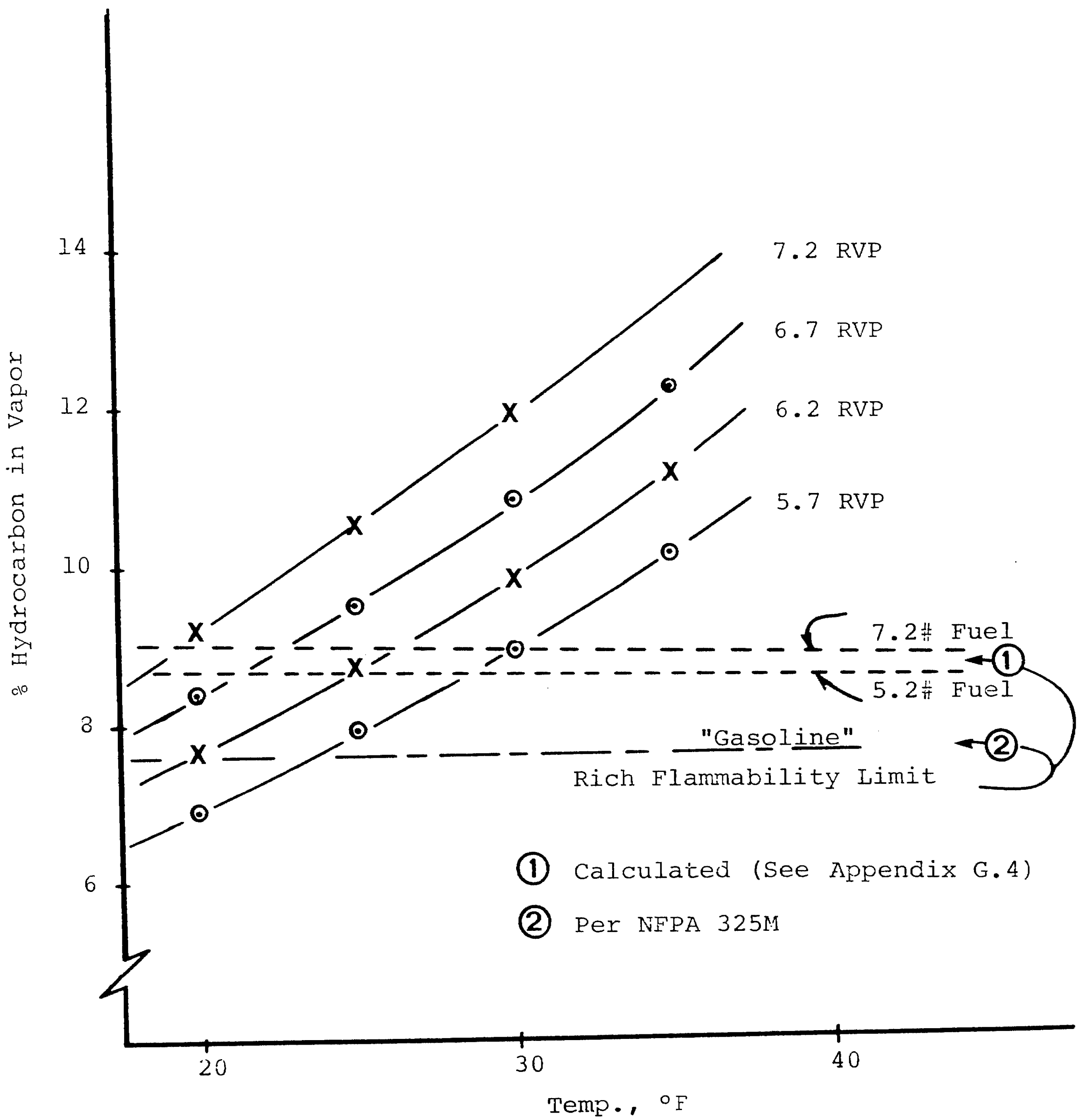

Figure 4-2. Flammability of Vapor Over Gasoline

4.3 REFINING IMPACT

This study included estimating the impacts, on three major categories of refining operations, of restricting summer gasoline vapor pressure. These categories are refining costs, raw material and energy requirements and capital requirements for facilities. Sensitivity of these assessments to certain exogenous factors has also been studied.

The bulk of the study effort on refining impacts was directed toward overall industry effects and derived from the use of a linear programming model of California's composite refining capability. A brief description of this model was presented in Section 3.3.1. Descriptions of certain aspects and details of this model have been included as appendices to this report. Future product demands imposed on the model are discussed in Appendix A. Projected crude supplies are discussed in Appendix B. Economics assumptions and factors are presented in Appendix C. Prior to construction of the LP model, operations (current and potential) associated with vapor pressure control were discussed with several California refiners. A summary of these interviews is presented in Appendix D.

A consequence, which will result if gasoline vapor pressure is restricted more than that presently required, is the rejection of some amount of low-boiling hydrocarbons from gasoline formulation. Alternative disposition of these low-boiling hydrocarbons is to fuel systems for refining process energy and for power generation. The modeling requirements to properly assess the implications of this alternative disposition are discussed in Appendix F. Pertinent elements of these appendices are included in the later presentations of detailed results.

It is appropriate, at this point, to discuss the use of the LP model and to identify the cases which were run. Two cases, with gasoline vapor pressure limited to 9 psi[1] maximum were run to establish base cases for 1985 and 1990. With the exceptions of atmospheric and vacuum crude distillation and of butane isomerization, all fuel products processes were allowed to be built or expanded. Alaskan North Slope (ANS) crude was defined as the marginal crude at a laid-in cost of $29.80 per barrel. Iso-butane and normal butane were also made available, at costs of $32.90 and $30.10 per barrel, respectively. Methane as a feed for hydrogen manufacture was given a cost equivalent to $5.48 per million Btu. Sales of two products, namely, propane LPG and petroleum coke, were allowed to vary at prices of $21.00 per barrel and $4.23 per fuel-oil-equivalent barrel, respectively. The latter is equivalent to $20 per short ton. Both prices are based on recent market price ratios to the cost of crude oil. All costs and net-back values used in the study are in terms of constant 1982 dollars.

Because the data source from which demand forecasts were developed includes refinery energy in the industrial energy category, it was necessary that the 1985 base case be run with raw energy as an available external source. This source was given an estimate cost of $5.48 per million Btu on the assumption that low sulfur-content and medium sulfur-content fuel oil will be the marginal source of industrial energy[2]. Using the quantity of purchased raw energy

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[1]Actual RVP specifications were defined to recognize a blending tolerance of 0.3 psi. Thus, the maximum RVP for base case runs was 8.7 psi.

[2]Weighted average of the incremental costs of low and medium sulfur-content fuel oils from the 1985 base case confirmed the estimated cost.

required by the 1985 base case, volume equivalents of low sulfur-content and medium sulfur-content fuel oils were determined using the ratio of forecasted demands for these two fuels. Demands for fuel oils were then reduced by the calculated volume equivalents of purchased energy for all subsequent cases, which were allowed to utilize fuel oils as well as plant fuel gas as energy sources. In this way, each case reflects an energy cost based on the incremental cost of fuel oil for that case and protects the energy demand associated with the forecast being used while allowing for changes in refining energy requirements associated with changes in RVP limits.

Each subject case was constrained to a particular vapor pressure limit, namely, 8 or 7 or 6 psi[1]. Variable raw materials and by-products economics were the same as those defined for the base cases. Initial major process capacities for subject cases were defined, however, as those utilized in the respective base case solutions. Crude distillation capacities were exceptions since it is recognized that the industry is expected to remain in a surplus status, even with recent shut-downs of some plants. Limiting initial capacities in this manner allows the subject case results to reflect the need for new and expanded capacity required to meet more restrictive vapor pressures. Even though individual refineries may have surplus capacity on some down-stream processes, this procedure recognizes that the industry as a whole has not invested in facilities for low-vapor-pressure control and, thus, use of facilities for

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[1]A constant vapor pressure blending tolerance of 0.3 psi was applied in each case, thus limits were 7.7, 6.7 and 5.7 psi, respectively.

that purpose precludes subsequent use as planned. At some point, the refining industry would have to replace capacity utilized in meeting restricted volatility to accommodate whatever was originally planned for those facilities.

4.3.1 Industry-Level Impacts

Four categories of cost impacts have been derived from the LP model results. Associated with each is an operational aspect of interest. These are discussed in the following subsections. Each is derived from the differences between base and subject case results for each of two future periods, namely 1985 and 1990. The first three categories, raw material costs, capital related costs and operating costs, are directly related to refining. The fourth, disposal costs, may be associated with refining but could be incurred wherever the rejected light hydrocarbons are used.

4.3.1.1 Raw Material Impacts

When butanes and pentanes are rejected from gasoline blending in order to achieve a lower vapor pressure, additional crude must be processed to make up for the lost gasoline volume. Because butane has a high octane rating, its rejection requires additional processing to compensate for lost octane quality. Both of these processing needs require more energy than is available from the rejected light hydrocarbons, thus requiring still more crude to be processed.

Because the model was allowed to produce propane LPG and petroleum coke as by-products, their volumes priced at their net-back values must be recognized in determining the net cost of increased raw material requirements. As shown in Table 4-13, the value of increased production of by-product is insufficient to offset increased crude costs.

TABLE 4-13

CHANGES IN RAW MATERIAL COST
(M$/D Above Base Case)

	Max RVP for 1985			Max RVP for 1990		
	8	7	6	8	7	6
ANS	298.7	634.2	1060.5	257.2	526.2	985.2
LPG	-85.1	-195.9	-300.6	-59.4	-107.9	-224.1
COKE	-4.5	-9.2	-18.4	-4.4	-8.7	-17.6
Net	209.1	429.1	741.5	193.4	409.6	743.5

The volume of additional ANS crude associated with changes in vapor pressure limits can be viewed as that shown by the LP model results. It can be argued, however, that by-product increases will offset energy demands and, at constant energy demand, reduce the need for additional crude, on an energy-equivalent basis[1]. Table 4-14 shows the additional crude as derived from model results and adjusted for the energy equivalents of by-products[2].

TABLE 4-14

CHANGES IN RAW MATERIAL REQUIREMENTS
(MBPD Above Base Case)

	Max RVP for 1985			Max RVP for 1990		
	8	7	6	8	7	6
ANS, (as such)	10.0	21.3	35.6	8.6	17.7	33.1
ANS, (adjusted)	6.3	13.1	21.9	5.7	12.2	21.8
ANS, (adjusted for LPG only)	7.5	15.5	26.8	6.9	14.5	26.5

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[1]Reducing gasoline vapor pressure increases its average density slightly and, as a consequence, its heating value (i.e. volumetric energy content). For this study, no adjustment to gasoline demand was made to account for the potential increase in mile-per-gallon efficiency which would theoretically occur.

[2]Factors used are: ANS=0.614(LPG) and ANS=1.13(COKE)

Also shown in Table 4-13 is the additional ANS crude adjusted for only LPG on the basis that marginal coke productions is sold as exported fuel and would not contribute to California's energy supply.

Process energy changes account for part of the net raw material changes. As shown in Table 4-15, energy changes, in terms of equivalent ANS crude, represent from 20 to 30 percent of the adjusted ANS increase shown in Table 4-13. Examination of changes in energy content of gasoline and distillate fuel production shows most of the energy-balance discrepancy to be accounted for by gasoline[1]. If all of the energy-balance mismatch were associated with gasoline heating value changes, its specific gravity would have to increase by approximately 0.8 percent per unit decrease in RVP. LP results, on the other hand, show an increase of approximately 0.6 percent per unit decrease in RVP.

TABLE 4-15

INCREASED ENERGY REQUIREMENTS
(Above Base Case)

	Max RVP for 1985			Max RVP for 1990		
	8	7	6	8	7	6
Btu,MMM/D	7.1	16.3	25.6	9.8	22.4	35.7
Equiv.ANS*, MBPD	1.3	2.9	4.5	1.7	3.9	6.3

*ANS=5.66 MMBTU/BBL

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[1]Heavy fuel production is adjusted internally to satisfy a fixed energy demand.

4.3.1.2 Capital Related Impacts

Changing vapor pressure limits requires expanded facilities to process the additional crude required to replace lost gasoline volume and to supply additional process energy. New facilities are also required to separate "contained" light hydrocarbons from various blend stocks to achieve RVP limits of 7 psi and lower. Investment amortization and interest, operating labor, maintenance, insurance, ad valorum taxes and overhead associated with new and expanded facilities require additional income. Further, federal and state income taxes on the additional income must also be received as additional revenue. Table 4-16 summarizes the capital related costs derived from the LP model results. Capital recovery costs are those for amortization, interest and income taxes[1]. Expenses are all other capital-related costs.

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[1] Income taxes, which are affected by depreciation credits, vary from year to year. A daily average can, however, be calculated from the present value of the stream of tax payments and applied as a fraction of the capital recovery. For the financial factors used in this study, the average tax payment is 0.12 times the capital recovery.

TABLE 4-16

CHANGES IN CAPITAL-RELATED COSTS

(M$/D Above Base Case)

	Max RVP for 1985			Max RVP for 1990		
	8	7	6	8	7	6
Capital Recovery	97.2	228.1	425.8	128.4	274.6	458.6
Related Expenses	27.0	66.2	129.9	38.3	79.1	129.0
TOTAL	124.2	294.3	555.7	166.7	353.7	587.6

Capital recovery changes reported in Table 4-16 were derived from investment differences between subject and corresponding base cases. Two classes of investment were recognized because certain facilities are related directly to changes in RVP limits and others are not. Auxiliary processes such as utility producers, amine scrubbers, etc. were treated as carrying variable and capital changes. Major process capacity changes, being related directly to changes in RVP limits, were assumed to be needed only during the summer-gasoline part of the year, namely, 6.4 months, or 194.7 days per year. Thus, capital must be recovered on this class of capacity at 1.875 times the recovery rate of processes operating year around.

Initial investments for each subject case, less the initial investment for the appropriate base case are shown in Table 4-17.

TABLE 4-17

CHANGES IN CAPITAL INVESTMENT
(MM$ Above Base Case)

	Max RVP for 1985			Max RVP for 1990		
	8	7	6	8	7	6
Major processes	72.1	169.2	315.8	95.3	203.0	340.2
Minor processes	6.7	15.8	29.5	8.9	19.0	31.7
Refining Total	78.8	185.0	345.3	104.2	222.7	371.9
Disposal facilities	12.9	25.0	58.4	12.6	26.8	49.6
Total Change	91.7	210.0	403.7	116.8	249.5	421.5

Also shown in Table 4-17 are the estimated capital requirements for disposal of rejected light hydrocarbons. Development of these latter is discussed in subsection 4.3.1.5.